

LOYOLA UNIVERSITY CHICAGO

RESOURCE COMPOSITION AND
MACROINVERTEBRATE RESOURCE CONSUMPTION IN THE
COLORADO RIVER BELOW GLEN CANYON DAM

A THESIS SUBMITTED TO
THE FACULTY OF THE GRADUATE SCHOOL
IN CANDIDACY FOR THE DEGREE OF
MASTER OF SCIENCE

PROGRAM IN BIOLOGY

BY

HOLLY ANN WELLARD KELLY

CHICAGO, IL

AUGUST 2010

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ACKNOWLEDGEMENTS

I have many people to thank for their help throughout graduate school. First, I must thank my family for their endless supply of encouragement, for always believing in me, and for instilling in me a love of the outdoors. I would like to acknowledge my mother and Sam for their help designing and sewing sampling nets. I owe a special thanks to my husband Sam for his love and support during the three years we spent apart. Finally, I thank all my friends, particularly my oldest friend Lindsey Good, for providing stress relieving activities, advice, and support throughout graduate school and life.

Thanks to everyone in the Rosi-Marshall Lab. In particular, I acknowledge Antoine Aubeneau for helping me write macros and learn new computer programs, and Paul Hoppe and Sarah Zahn, for their help with laboratory and field work. I owe great thanks to everyone on the Colorado River Ecosystems Studies Team, particularly the technicians, Amber Adams, Kate Behn, and Adam Copp, for preparing everything for river trips and collecting my samples when I was not there. I also thank Amber Ulseth, for her help in the field and for sharing her tent during inclement weather. Special thanks to the many boatmen, whose whitewater rafting knowledge and expertise made sampling possible, and whose great personalities made every river trip the time of my life.

I would like to especially thank my committee members and the principal investigators on my project: Dr. Martin Berg, Dr. Chris Peterson, Dr. Ted Kennedy, Dr. Colden Baxter, Dr. Bob Hall, and Dr. Wyatt Cross, for teaching me about stream

ecology, aquatic entomology, algal ecology, and statistics, and helping me to think critically about science and my project. I give my greatest thanks to my adviser, Dr. Emma Rosi-Marshall for her endless stream of ideas and guidance through this process. I could not have finished without her support. Thank you for teaching me and making graduate school so much fun.

Finally, I thank C. Donato, J. Kampman, S. Khan, D. Kincaid, D. Lee, S. Lee, J. Nunnally, K. Pfeifer, A. Salma, Y. Sayeed, J. Stanton, K. Vallis, T. White, M. Yard, for assistance with field and laboratory work, data analysis and editing. This work was supported by a grant from the United States Geological Survey, Grand Canyon Monitoring and Research Center.

This work is dedicated to my mother and father, Judd and Mary Ann Wellard, my brother and sister, Scott and Ann Wellard, and my husband, Sam Kelly, for their unconditional love and support throughout my life and the course of this thesis.

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CHAPTER ONE

MACROINVERTEBRATE RESOURCE CONSUMPTION IN THE
COLORADO RIVER BELOW GLEN CANYON DAM

Abstract

Physical and biological changes to rivers induced by large dams can significantly impact downstream communities, decreasing the biotic integrity of these rivers. The completion of Glen Canyon Dam on the Colorado River in 1963 has altered the downstream ecosystem and contributed to the decline of native fish populations in the river. Macroinvertebrates are an important food resource for fish and determining the relative importance of basal resources to macroinvertebrate production will help guide the development of a long-term lower trophic level monitoring program. Because autochthonous production is high in the tailwater reach and tributary allochthonous carbon inputs are substantial at downstream sites, I predict that macroinvertebrate diets will reflect longitudinal changes in resource availability. I also predict that seasonal changes in resource availability due to monsoon tributary flooding in the autumn and lower light availability in the winter, will amplify the longitudinal change in resource use by macroinvertebrates. I examined the diets of the common macroinvertebrates (*Simulium arcticum*, *Gammarus lacustris*, *Potamopyrgus antipodarum*, and chironomids) at six sites below Glen Canyon Dam during all seasons. Macroinvertebrate diet composition was compared to the composition of the epilithon (rock faces), epicremnon

(cliff faces) communities, and the suspended organic seston. The relative contribution of autochthonous and allochthonous resources to macroinvertebrate production was calculated at all six sites. In general, macroinvertebrate diets tracked downstream changes in resource availability in the river, and autochthonous resources were consumed in greater proportions in the tailwaters while more allochthonous resources were consumed downstream. Also autochthonous resources contributed more to macroinvertebrate production in the tailwaters and allochthonous resources contributed more downstream. The extent of diet shifts depended on consumer identity and season. Diets of *S. arcticum* differed among all seasons, whereas the diets of other taxa only differed during the autumn and winter. Allochthonous resources were most important for all consumers during the monsoon season (July-September), when tributaries can contribute significant amounts of organic matter to the mainstem. These data demonstrate that both autochthonous and allochthonous resources support macroinvertebrate production in the Grand Canyon; however, the contribution of allochthonous resources to macroinvertebrate production increases at downstream sites.

Introduction

Large dams alter the physical habitat, temperature and flow regimes of rivers and have contributed significantly to the degradation of freshwater ecosystems worldwide (Baxter 1977, Ward and Stanford 1979, Petts 1984, Nilsson and Berggren 2000). The physical changes induced by dams can significantly affect riverine biodiversity and food webs (Power et al. 1996), often reducing biodiversity of algae, macroinvertebrate and fish communities (Allan and Flecker 1993). Dam-induced physical and chemical changes in

ivers are most drastic in the tailwaters where non-native taxa often thrive (Stanford et al. 1996). Tributaries downstream of dams ameliorate the effects of dams on rivers physical and chemical properties (Ward and Stanford 1983); therefore, communities that are downstream of tributaries may differ from tailwater communities (Takao et al. 2008).

The Colorado River has been physically and biologically altered due to construction of Glen Canyon Dam (Blinn and Cole 1991). Historically, the river had high seasonal variability in temperature and discharge (Topping et al. 2003), was at times extremely sediment-laden (Wright et al. 2005), and sustained a highly endemic native fish community (Gloss and Coggins 2005) and diverse macroinvertebrate populations (Musser 1959, Edmunds 1959, Haden et al. 2003, Hofnecht 1981, Oberlin et al. 1999). Dam-associated alterations in the physical template and intentional and unintentional introductions of non-native fishes and macroinvertebrates have significantly altered food web structure, and four of the eight species of fish native to Grand Canyon have been locally extirpated while one of the remaining species, humpback chub (*Gila cypha*), is federally endangered (Minckley et. al 2003).

A variety of factors may limit populations of native fish in Grand Canyon including habitat availability, competition with and predation by non-native species, and food resource availability (Gloss and Coggins 2005). Macroinvertebrates are an important food resource for fish throughout the lower Colorado River basin (Childs et al. 1998, Zahn et al. unpublished data) and declines in native fish populations may be due to food limitation (i.e. low macroinvertebrate production) at the base of the food web. To successfully manage this highly modified ecosystem to support macroinvertebrate and

native fish populations, it is crucial to understand the food resources (allochthonous vs. autochthonous) supporting the base of the food web and how energy flows through the food web. An important first step in elucidating energy flow through the entire food web is to assess food resources consumed by macroinvertebrates.

Limited literature documents the pre-impoundment macroinvertebrate communities of the Colorado River in Grand Canyon (Blinn and Cole 1991). Musser (1959) surveyed macroinvertebrate species from the Colorado River in Glen Canyon and reported 91 species from the following eight orders: Ephemeroptera, Odonata, Hemiptera, Megaloptera, Trichoptera, Lepidoptera, Coleoptera, and Diptera. Although collection methods are not clearly reported, the majority of species were collected from tributaries, and only 247 of the 2,315 individuals collected were from the mainstem (Musser 1959). Edmunds (1959) reports six families and eight genera of mayflies in the area of Glen Canyon Dam before impoundment. The macroinvertebrate fauna of Cataract Canyon, an unregulated reach of the Colorado River immediately upriver of Lake Powell, is likely analogous to pre-impoundment Colorado River conditions because this reach is geomorphically similar to Grand Canyon and has suspended sediment concentrations and discharge regimes that closely match pre-impoundment conditions (Stanford and Ward 1986, Haden et al. 2003). Forty-nine macroinvertebrate taxa were identified in this reach, with most taxa from the orders, Ephemeroptera, Plecoptera, Trichoptera, and Diptera (Haden et al. 2003).

Post-impoundment studies of macroinvertebrate communities in tributaries of the Colorado River through Grand Canyon may also provide useful indicators of the

mainstem pre-impoundment macroinvertebrate community (Hofnecht 1981, Oberlin et al. 1999). Between 23-52 macroinvertebrate families have been reported in tributaries throughout the Grand Canyon (Hofnecht 1981, Oberlin et al. 1999), with representatives of the order Trichoptera the most diverse, comprising nine families and twelve genera (Oberlin et al. 1999). In addition, macroinvertebrates from six orders: Ephemeroptera, Lepidoptera, Diptera, Megaloptera, Coleoptera, and Plecoptera, are present in tributaries (Oberlin et al. 1999).

Numerous pre-impoundment studies of the Green River, Utah, approximately 180 miles upstream from Glen Canyon Dam, may provide additional insight into the pre-dam Colorado River Grand Canyon macroinvertebrate community assemblage (Vinson 2001). Prior to the completion of the Flaming Gorge Dam in 1962, the Green River supported a diverse macroinvertebrate community (Pearson et al. 1968, Vinson 2001) including species within the orders: Nematoda, Oligochaeta, Hirudinea, Amphipoda, Hydracarina, Plecoptera, Ephemeroptera, Odonata, Hemiptera, Megaloptera, Trichoptera, Lepidoptera, Coleoptera, Diptera, and Gastropoda. Most of the taxa reported above were extirpated after the completion of the Flaming Gorge Dam (Vinson 2001).

Today, the Colorado River below Glen Canyon Dam has a depauperate macroinvertebrate community dominated by non-native species (Cross et al. in review). Plecoptera, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Lepidoptera, and Coleoptera are rare in the mainstem and restricted to areas close to the mouths of tributaries, suggesting that tributaries are the source for these individuals (personal observation). The invasive New Zealand mud snail, *Potamopyrgus antipodarum*, and the

introduced amphipod, *Gammarus lacustris*, dominate the biomass of the macroinvertebrate community in the Glen Canyon tailwater reach (Stevens et al. 1997, Cross et al. in press). In the downstream reaches (226 miles (363 km) starting after the first tributary enters the mainstem ca. 16 miles (25 km) downstream of Glen Canyon Dam), the community is dominated by a non-native, filter-feeding dipteran, *Simulium arcticum*, and various collecting-gathering Chironomidae (Stevens et al. 1997, Cross et al. unpublished data). Other macroinvertebrates present throughout the system include: Lumbricidae, Tubificidae, Physidae, Ostracoda, Hydracarina, Planariidae, and Empididae (Stevens et al. 1997, Cross et al. unpublished data).

Macroinvertebrates can be classified into functional feeding groups based on their mode of food acquisition (Cummins 1973, Cummins and Klug 1979). The dominant macroinvertebrates in the Colorado River fall into four such groups: collector-filterers (*Simulium arcticum*), collector-gatherers (Chironomidae), scrapers (*Potamopyrgus antipodarum*), and shredders (*Gammarus lacustris*). Collector-filterers generally feed on fine particulate organic matter (FPOM, particles <1mm) suspended in the water column (Wallace and Merritt 1980), and collector-gatherers feed on FPOM deposited on the benthos (Cummins and Klug 1979). Scrapers are noted for grazing on periphyton or food that is attached to a surface (Cummins and Klug 1979). Shredders feed on coarse particulate organic matter (CPOM, particles >1mm), such as terrestrial leaves and macrophytes. *Gammarus* are generally classified as shredders, but have also been reported to feed on other macroinvertebrates and small fish, and therefore may also be categorized in the functional feeding group, predators (Kelly et al. 2002, Macneil et al.

1997). Although chironomids are most commonly classified as collector-gatherers, chironomid larvae ingest a wide variety of food items and may also be categorized as collector-filterers, collector-miners, shredders, scrapers, and predators (Berg 1995, Henriques-Oliveira et al. 2003, Ferrington et al. 2008). Finally, simuliids are also known to be capable of scraping surfaces with their mandibular teeth (Wallace and Merritt 1980, Currie and Craig 1987).

Classifying macroinvertebrates into functional feeding groups is useful as it allows for classification based on how macroinvertebrates acquire their food resources, rather than categorizing them exclusively based on diet (Cummins and Klug 1979, Merritt et al. 2008). Many macroinvertebrates are omnivorous and often opportunistic; therefore, species-specific diet shifts in a given system may be attributed to seasonal and/or spatial changes in organic matter availability. Also in altered systems where marked changes in the physical and chemical characteristics result in altered availability of food resources, facultative (generalist) consumers may be better suited to maintain healthy populations than obligate (specialist) consumers (Cummins and Klug 1979). Classifying macroinvertebrates by functional feeding groups is useful for predicting general patterns in food resource use and community structure in stream ecosystems. However, in systems where food resources shift quickly and drastically, diet analysis may be a more sensitive metric indicating change.

Few studies have quantified the diets of the dominant macroinvertebrates in the Grand-Canyon reaches of the Colorado River. Pinney (1991) reported the diets of *Gammarus lacustris* in the tailwaters collected from March 1986 to January 1987. Diets

consisted, primarily, of diatoms (>93%), along with small amounts of *Cladophora glomerata*, cyanobacteria, and red algae. Chironomid diets, examined in the tailwaters and at multiple sites downstream, were comprised of greater than 60% algae (mostly diatoms) in the tailwaters, and only 31% algae (mostly diatoms) and 69% detritus, bacteria and sand at downstream sites (Stevens et al. 1997).

It has been suggested that in this system allochthonous resources contribute little to macroinvertebrate production (Walters et al. 2000), presumably due to its low quality. Stevens and others (1997) documented amorphous detritus likely of allochthonous origins in the guts of macroinvertebrates, but Stevens and others (1997) did not determine the relative contribution of allochthonous resources to macroinvertebrate production. Allochthonous resources are a dominant food item for macroinvertebrates in many systems (Hynes 1975, Vannote et al. 1980, Gregory et al. 1991, Polis et al. 1997, Wallace et al. 1997, Hall et al. 2000, Hall et al. 2001, Rosi-Marshall and Wallace 2002) and macroinvertebrate diets often shift to match changes in resource availability (Rosi-Marshall and Wallace 2002). Allochthonous resources have the potential to be an important, but unmeasured, resource supporting macroinvertebrate production in the Colorado River system.

The relative importance of *in situ* algal production in the tailwaters or allochthonous inputs from tributaries in supporting macroinvertebrate production, has not been extensively studied, but hypotheses on the form of these relationships can be formulated (Figure 1). The completion of the Glen Canyon Dam in 1963 substantially reduced sediment loads in the river, increasing light levels and algal production in the

tailwaters below the dam and downstream (Stevens et al. 1997). In addition, organic matter inputs from upstream were reduced. Downstream tributaries increase turbidity which reduces light levels and algal production (Yard 2003, Hall et al. unpublished data). But tributaries are also a source of allochthonous organic matter into the mainstem Colorado River and can dominate downstream carbon budgets (Kennedy et al. unpublished data) (Figure 1). Stable isotope food-web analysis by Angradi (1994) indicates that aquatic secondary production in Glen Canyon (tailwaters) is fueled by autochthonous carbon, but terrestrial riparian and upland vegetation may be important to downstream food webs. Therefore, the organic matter budget in the river shifts longitudinally from autochthonous to allochthonous resources (Kennedy et al. unpublished data) and food resources consumed by macroinvertebrates may shift accordingly. This has been demonstrated in other systems ranging from headwaters to large rivers (Vannote et al. 1980, Tavares-Cromar and Williams 1996, Benke and Wallace 1997, Hall et al. 2000, Hall et al. 2001, Rosi-Marshall and Wallace 2002, Cross et al. 2007).

Seasonal changes in resource availability due to monsoon tributary flooding in the autumn and lower light availability in the winter may amplify the longitudinal change in resource use by macroinvertebrates. For example, in the Little Tennessee River, macroinvertebrate diets reflected spatial and seasonal changes in resource availability (Rosi-Marshall and Wallace 2002). In the Colorado River basin, the Arizona monsoon season (July to September) brings high precipitation to the basin, and increases tributary flooding and suspended sediment and allochthonous organic matter inputs to the

mainstem (Kennedy et al. unpublished data). The high suspended sediment load reduces light levels and primary production, and may amplify the relative importance of allochthonous organic matter to macroinvertebrate consumers. Reliance on allochthonous organic matter may continue during the winter months because of low light availability due to high canyon walls (specifically along east-west reaches of the river) (Yard et al. 2005). A monsoon season shift in diets of macroinvertebrates dwelling in the tailwaters of the dam should not occur because it is upstream of tributaries and has continuously clear water. However, during winter months reduced light may reduce primary production in both the tailwaters and downstream sites.

The objective of this study was to examine how the use of allochthonous and autochthonous resources by resident macroinvertebrates changes seasonally and spatially (with distance from the dam and in relation to tributaries). To address this objective, I examined the diets of the common macroinvertebrates at six sites below Glen Canyon Dam during all seasons. To address the extent that macroinvertebrate diets reflect longitudinal and seasonal changes in *in situ* resource availability, I examined resource composition of the epilithon (rock faces), epicremnon (cliff faces) communities, and suspended organic seston and compared the composition of these resources to macroinvertebrate diets.

I predict that macroinvertebrate diets change with distance from the dam and reflect a change in resource availability, specifically shifting from reliance on autochthonous production in tailwaters to an allochthonous resource base downstream (Table 1). I also predict that magnitude of downstream shifts in resource availability and

consumption will increase during the monsoon season (July to September) when the river is turbid, and in the winter when there is low light. During these seasons, I predict that macroinvertebrates will consume mainly allochthonous resources. Evaluating both downstream and seasonal shifts in macroinvertebrate diets will help to elucidate the relative role of allochthonous carbon in supporting the food webs of the Colorado River, Grand Canyon.

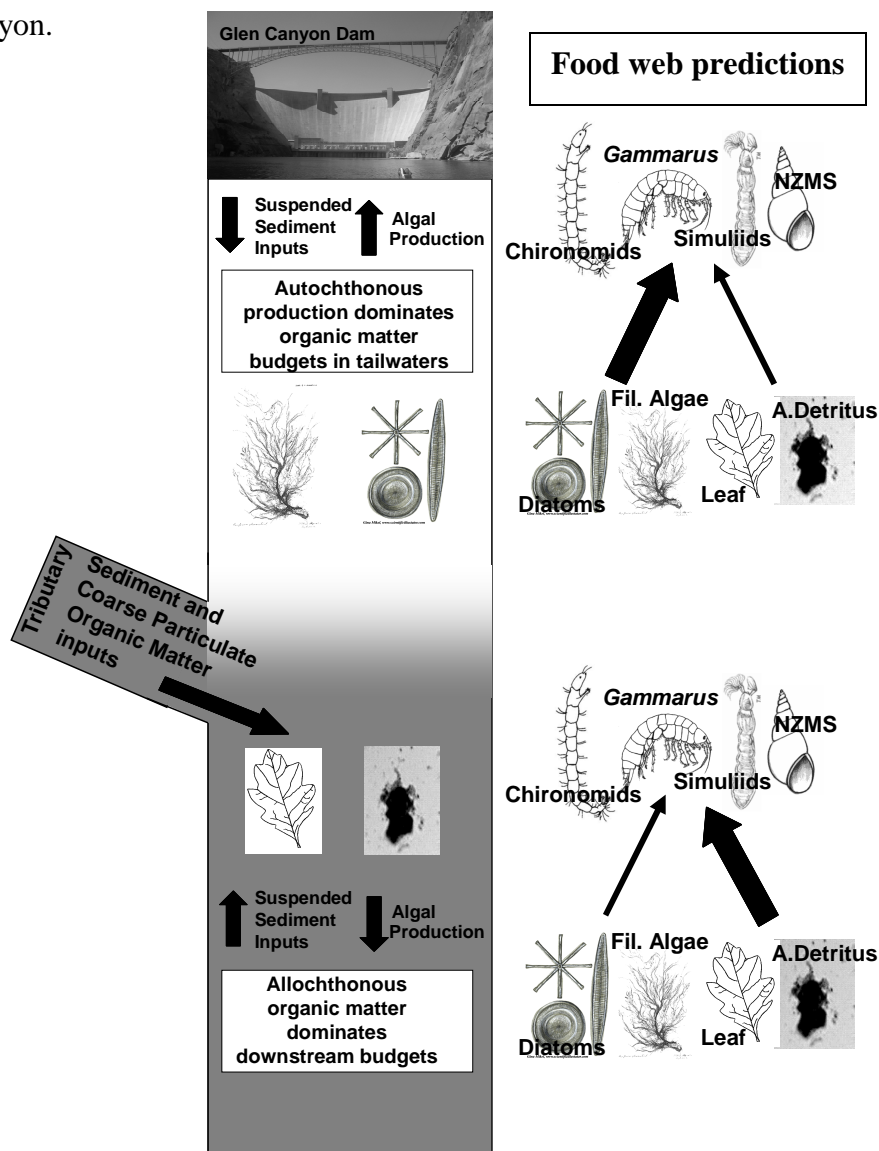


Figure 1. Effects of the dam and tributary inputs on organic matter budgets and potential influence on macroinvertebrate food web.

Table 1. Site, season, and month of sample collection, and associated light condition, water condition, average monthly sediment concentration (mg/L), and prediction describing which resources (autochthonous or allochthonous) will be predominately consumed by macroinvertebrates. L = low, M = moderate, H = high, AUT = autochthonous, and ALLO = allochthonous.

Site (RM)	Season	Month	Light	Turbidity	Average Monthly Sediment Concentration mg/L (SD)	Predictions for macroinvertebrate resource consumption
0	Summer	June 2006	H	L	0.1 (0.13)	AUT
30	"	"	H	M	127 (87)	ALLO
62*	"	"	H	M	169 (115)	ALLO
127*	"	"	H	M	169 (115)	ALLO
165**	"	"	H	M	203 (180)	ALLO
225	"	"	H	M	203 (180)	ALLO
0	Autumn	September 2006	M	L	0.25 (0.26)	AUT
30	"	"	M	M	167 (245)	ALLO
62*	"	"	M	H	1291 (1534)	ALLO
127*	"	"	M	H	1291 (1534)	ALLO
165**	"	"	M	H	1559 (1440)	ALLO
225	"	"	M	H	1559 (1440)	ALLO
0	Winter	January 2007	L	L	1.18 (0.30)	AUT
30	"	"	L	M	154 (75)	ALLO
62*	"	"	L	M	181 (91)	ALLO
127*	"	"	L	M	181 (91)	ALLO
165**	"	"	L	M	229 (72)	ALLO
225	"	"	L	M	229 (72)	ALLO
0	Spring	April 2007	M	L	0.85 (0.36)	AUT
30	"	"	M	M	59 (26)	ALLO
62*	"	"	M	M	93 (33)	ALLO
127*	"	"	M	M	93 (33)	ALLO
165	"	"	M	M	143 (82)	ALLO
225	"	"	M	M	137 (114)	ALLO

*Sediment concentration data was collected at RM 88. **Sediment concentration data was collected at RM 225. Monthly sediment concentration data was calculated using Grand Canyon acoustic sediment data from the following USGS stations: Colorado River at river-mile 30, Colorado River near Grand Canyon AZ (09402500), Colorado River above National Canyon near Supai AZ (09404120), Colorado River above Diamond Creek near Peach Springs AZ (09404200). RM 0 sediment concentrations were estimated by calculating the ash-content dry mass of suspended fine (siston) and coarse particulate matter samples, collected monthly. Sediment concentration is the sum of silt/clay concentrations and sand concentrations. The average monthly concentration was calculated using data collected at 15 minute intervals at each site. Water conditions were classified as low turbidity if sediment concentrations were less than 50 mg/L, moderate turbidity if sediment concentrations were greater than 50 mg/L, and high turbidity if sediment concentrations were greater than 250 mg/L.

Methods

Study sites and sampling protocol

This study was conducted in the Colorado River (CR) in Grand Canyon, Arizona (36° 03'N, 112° 09' W). Six sites were sampled over a 226 mile (363 km) reach downstream of Glen Canyon Dam (GCD) (Figure 2). The use of river miles is the historical precedent for describing distance along the Colorado River in Grand Canyon; therefore, I report distances in miles, with kilometers in parentheses. Sites were selected based on general canyon characteristics, the location of major tributary inputs, prevalence of humpback chub populations (RM 62 and 127), and based on their long-term use as sediment and geomorphology monitoring sites (RM 30, 62 and 127). The first site, Lee's Ferry (RM 0) is located in Glen Canyon and encompasses a 15.7 mile (25 km) reach extending from the downstream end of the Glen Canyon Dam to Lee's Ferry. This tailwater reach is above the confluence of the Paria River, and is consistently low in turbidity. The five downstream sites are located in the Grand Canyon, from Marble Canyon to Diamond Creek. The second site, RM 30, is located in the Marble Canyon section (Redwall gorge reach) of the Grand Canyon, approximately 29 miles downstream of the Paria River, the first major tributary below the dam. The third site, RM 62, is located in the beginning of the Central Grand Canyon section (Furnace flats reach) below the Little Colorado River (LCR), the largest tributary. The fourth site, RM 127, is also located in the Central Grand Canyon section (Middle granite gorge reach) below a number of smaller tributaries including Bright Angel, Shinumo and Fossil Creeks. The fifth site, RM 165, is located in the Western Grand Canyon section (Lower canyon reach)

below Tapeats, Kanab and Havasu Creeks. The final site, RM 225, is also located in the Western Grand Canyon section (Lower granite gorge) and extends to Diamond Creek (a small tributary). Sites, RM 30 and 62, are located in wider sections of the canyon and sites, RM 127 and 165, are within the narrowest canyon sections (Stevens et al. 1997).

Mean site characteristics: discharge (m^3s^{-1}), catchment area (km^2), depth (m), and width (m), are presented in Table 2. Discharge increases from approximately $329 \text{ m}^3\text{s}^{-1}$ at RM 0 to $357 \text{ m}^3\text{s}^{-1}$ at RM 225. Catchment area increases from $289,560 \text{ km}^2$ at RM 0 to $386,726 \text{ km}^2$ at RM 225. Thalweg depth ranges from 6.3 meters at RM 0 up to 7.8 meters at RM 62. Width ranges from 60.8 meters at RM 127 up to 131.4 meters at RM 0. To examine the extent of seasonal variability in resource availability and consumption, I collected samples at each site and season during the following four months: June 2006 (moderate turbidity and high light conditions), September 2006 (high turbidity and moderate light conditions), January 2007 (moderate turbidity and low light conditions), and April 2007 (moderate turbidity and moderate light conditions) (Table 1). Water conditions were classified based on average monthly sediment concentrations (mg/L) for each site and season, and light conditions were classified based on seasonal changes in light conditions. Water conditions were classified as low turbidity if sediment concentrations were less than 50 mg/L, moderate turbidity if sediment concentrations were greater than 50 mg/L, and high turbidity if sediment concentrations were greater than 250 mg/L.

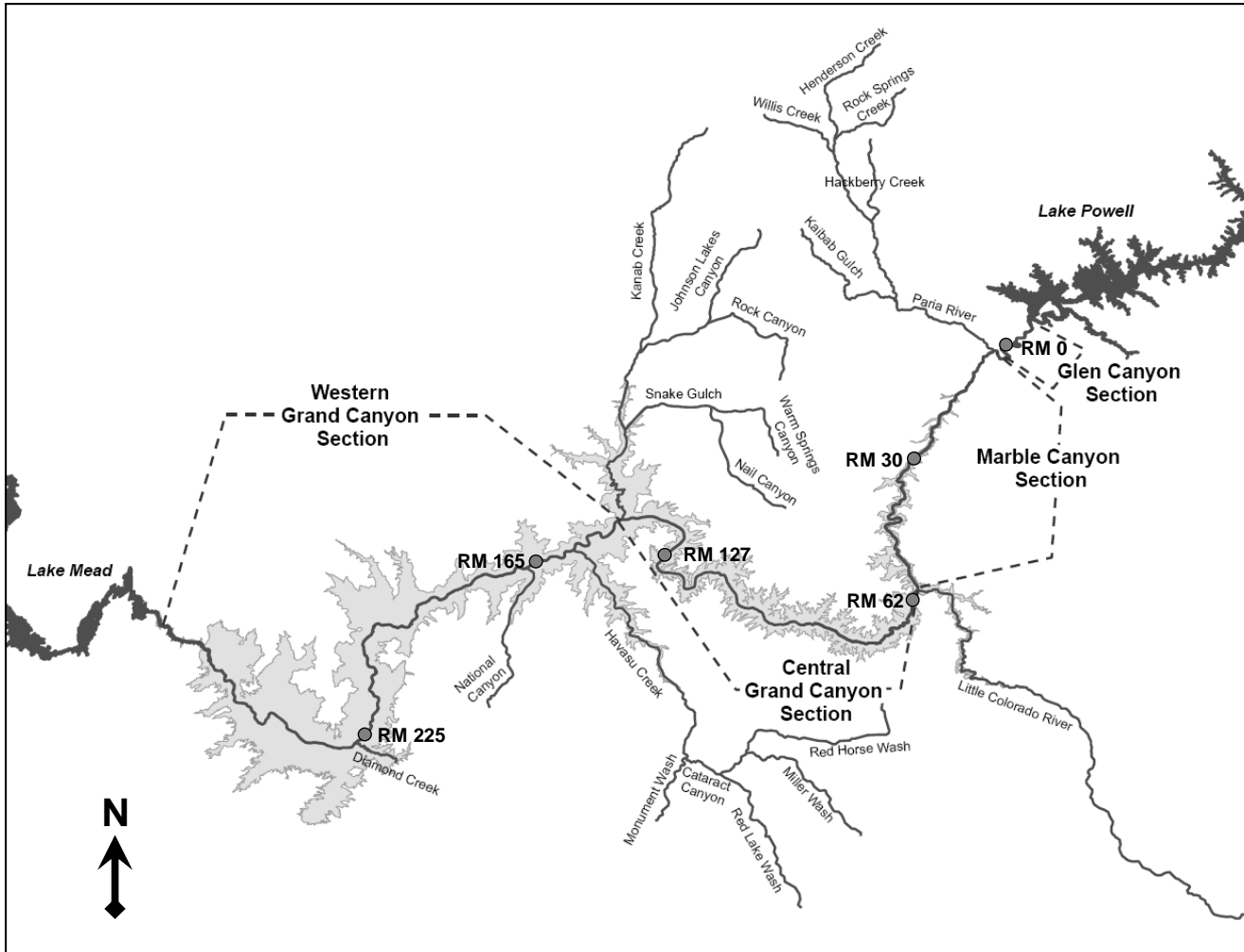


Figure 2. Map of the Colorado River in Grand Canyon showing the location of the six sites sampled.

Table 2. Mean site characteristics.

Site	Annual Discharge m ³ /s (SD)	Catchment area (km ²)	Depth (m)	Width (m)
RM 0	329.89(53.61)	289,560	6.3	131.4
RM 30	N/A	N/A	6.3	77.1
RM 60	> 346.68 (51.45)*	> 366,742*	7.8	110.3
RM 125			5.1	60.8
RM 165	NA	383,139	6.2	74.4
RM 225	357.66 (48.90)	386,726	6.8	82.5

* Site is located at RM 88. Annual discharge and catchment area were calculated using USGS Real-Time Water Data for Arizona. Annual discharge is calculated from the monthly mean discharges taken from June 2006 to May 2007. Catchment area is taken from the USGS station closest to the sites listed above. Average width and thalweg depth were estimated at a discharge of 226 m³/s.

Resource and macroinvertebrate collection

Suspended fine particulate organic matter (seston) composition samples (two to three per site and date) were collected from the thalweg at each site by sieving river water through a 250- μ m sieve and filtering ca. 40-300 ml onto 0.45- μ m gridded Metrical® membrane filters (Pall Corp., Ann Arbor, MI). Epilithic biofilms were scraped from two to three rocks collected from the river bed and from two to three cliff faces, using a scraping sucking device. A 30-40 ml subsample of biofilm slurry from individual rocks and cliffs was preserved in the field with Lugol's solution (Prescott 1978).

Macroinvertebrates were haphazardly collected throughout the reaches of the six sites, preserved in Kahle's solution (Stehr 1987) in the field, and returned to the lab for gut-content analysis.

Resource composition slide preparation

For epilithic and epicremnic biofilms, I filtered 0.1-5.0 ml subsamples from preserved field collections onto gridded Metrical® membrane filters (25 mm, 0.45 µm) (Pall Corp., Ann Arbor, MI). Seston, epilithic and epicremnic filters were mounted on slides for preservation using Type B immersion oil.

Macroinvertebrate slide preparation

Macroinvertebrate resource consumption was measured using gut-content analysis (Benke and Wallace 1980, Rosi-Marshall and Wallace 2002, Hall et al. 2000). I examined diets from each of the dominant taxa [*Simulium arcticum* (Insecta: Diptera: Simuliidae), *Gammarus lacustris* (Crustacea: Amphipoda: Gammaridae), chironomids (Insecta: Diptera: Chironomidae), and *Potamopyrgus antipodarum* (New Zealand mud snails; Gastropoda: Neotaenioglossa: Hydrobiidae)]. Dissected gut contents were drawn onto gridded Metrical® membrane filters (25mm, 0.45µm) (Pall Corp., Ann Arbor, MI) and mounted on slides for preservation using Type B immersion oil. Macroinvertebrates varied in size and gut fullness; therefore, to ensure that a sufficient number of particles were present on each prepared slide, the gut contents of one to four macroinvertebrates were filtered onto each slide. Two to four slides were analyzed for each taxon at each site and season.

Microscopy

A minimum of 50 individual particles on each slide were identified and their area was measured along random transects using image analysis software, ImagePro Plus® (Media Cybernetics Inc., Bethesda, MD), attached to a compound microscope at 100x

magnification (Rosi-Marshall and Wallace 2002). Particles were identified and categorized as: diatoms, filamentous algae, leaf material, fungi, macrophyte, animal material, cyanobacteria, red algae, and amorphous detritus (i.e. aggregations of organic subcellular-sized particles with no recognizable cellular structure [Bowen 1984, Mann 1988, Hall et al. 2000]). The area of each particle was measured and the proportion of each food resource in the seston, biofilms and diets was calculated.

Relative contribution of food types to production

Because food resources vary in quality, food-specific assimilation efficiencies (percentage of a food type that a macroinvertebrate is able to assimilate) and net production efficiencies (an estimate of the ratio of tissue production to energy assimilation) were used to estimate the relative contribution of food types to production. The assimilation efficiencies (AE) used were as follows: 30% for diatoms and filamentous algae; 50% for fungi; 10% for amorphous detritus, macrophytes, leaf material and cyanobacteria; and 70% for animal (Benke and Wallace 1980). Because I did not measure production efficiencies for the species in this study, I assumed a net production efficiency (NPE) of 0.5, based on the available literature (Benke and Wallace 1980). For each food resource the relative contribution (RC) of the food type ($G_{\text{food type a...n}}$) to production was calculated as follows:

$$RC = (G_a) \times AE \times NPE / \sum (G_{(a+b+c...n)} \times AE \times NPE).$$

Estimating the origin of amorphous detritus

A common food resource for macroinvertebrates in many large river systems, including the Colorado River, is amorphous detritus (Benke and Wallace 1997, Stevens et

al. 1997, Rosi-Marshall and Wallace 2002). Amorphous detritus can be autochthonously and/or allochthonously derived because it is often formed via flocculation of dissolved organic matter (DOM) and may be composed of: bacteria, microbes, exopolymeric secretions from bacteria, algae and fungi, sediment particles, and small detrital fragments (Mann 1988, Decho and Moriarty 1990, Carlough 1994, Hall et al. 2000, Hart and Lovvorn 2003). In the Colorado River, autochthonous production is high in the tailwater reach and inputs of tributary allochthonous carbon increase downstream. Therefore, amorphous detritus may shift from being autochthonously derived in the tailwater to allochthonously derived downstream. Based on this observation, I assumed that all amorphous detritus in the tailwaters is derived from algae, and I used the ratio of amorphous detritus to diatoms in tailwater epilithic biofilms to calculate the autochthonous fraction (AF) of amorphous detritus in downstream macroinvertebrate diets. I calculated AF for each season, and used season-specific ratios developed from the tailwaters to estimate the fraction of amorphous detritus that was autochthonous at the downstream sites. For each macroinvertebrate diet, I calculated the AF of amorphous detritus based on the percent diatoms in the diet.

I applied adjusted amorphous detritus proportions to estimate the relative contribution of autochthonous (diatoms + filamentous algae + autochthonously derived amorphous detritus) versus allochthonous (leaf material + allochthonously derived amorphous detritus) resources to the production of each macroinvertebrate taxon. Seasonal estimates for each taxon were averaged to estimate the relative contribution of autochthonous and allochthonous resources to production over the course of the year. To

compare the downstream system to the tailwaters, I averaged the allochthonous and autochthonous resource consumption by each taxon at downstream sites.

Statistical analyses

Statistical analyses were performed using the software package Systat® (v. 10.0) (SSI San Jose, California). I compared proportions of dominant food resources consumed by macroinvertebrates (diatoms, filamentous algae, amorphous detritus and leaf material), among sites and seasons, using two-way analysis of variance (ANOVA). Differences in proportions of particle types comprising seston, rock faces, and cliff faces were also analyzed using two-way ANOVA. All proportions were arcsine-square-root transformed before analysis to meet the normality assumption for ANOVA. When two-way ANOVA analyses resulted in a significant site \times season interaction, I analyzed each factor independently by site or season using one-way ANOVA and Tukey's HSD test. For consistent reporting and analysis of the results, statistical analyses that did not result in a significant interaction were also analyzed using one-way ANOVA and Tukey's HSD test. For one-way ANOVA analyses, a Bonferroni-adjusted p -value of $0.05/4 = 0.0125$ was used to compare proportions for dominant particle types among sites for each season ($n = 4$), and a p -value of $0.05/6 = 0.0083$ was used to compare proportions among seasons for each site ($n = 6$).

Characterization of resources – correlation analysis

I used correlation analysis to assess the degree of correspondence between macroinvertebrate diets and the availability of food resources in the river. For each of the dominant particle types (diatoms, filamentous algae, amorphous detritus and leaf

material), I examined the relationship between percent composition of the particle type in a particular feeding habitat (seston, rock and cliff face biofilms) and percent consumption of the particle type by each taxon, at each site and season. For example, the percent diatoms in the seston at each site during each season were compared to the percent diatoms in the gut contents of *S. arcticum* collected concurrently. Pearson product-moment correlation coefficient (r) was used to assess the strength of the association between the two variables (or the strength of the linear dependence).

Results

For clarity, the dominant patterns observed are discussed in each section of the results and significant differences (p -values, F , and degrees of freedom) are reported in appendices. I calculated the fraction of autochthonously derived amorphous detritus (AF) at downstream sites, to be less than 37 percent during all seasons. Therefore, when I refer to amorphous detritus in the results, I consider it an allochthonous resource. However, the calculated autochthonous and allochthonous fractions of amorphous detritus were applied to the production attributable results.

Composition of available resources

Suspended organic seston

Suspended organic seston composition was dominated by autochthonous resources (diatoms + filamentous algae) in the clear tailwater reach (RM 0) during all seasons (Figure 3, Table 3, Appendix 1 and 2). Along downstream reaches (RM 30 – RM 225), suspended organic seston was dominated by allochthonous resources (amorphous detritus + leaf material) in all seasons except during moderate turbidity conditions in

spring, when diatoms were the dominant particle type at four of five sites (Figure 3, Table 3, Appendix 1 and 2). The greatest changes in seston resource composition occurred during high turbidity and low light conditions in the autumn and winter, when there were significantly higher proportions of amorphous detritus at most downstream sites than in the tailwaters (Figure 3, Table 3, Appendix 1 and 2).

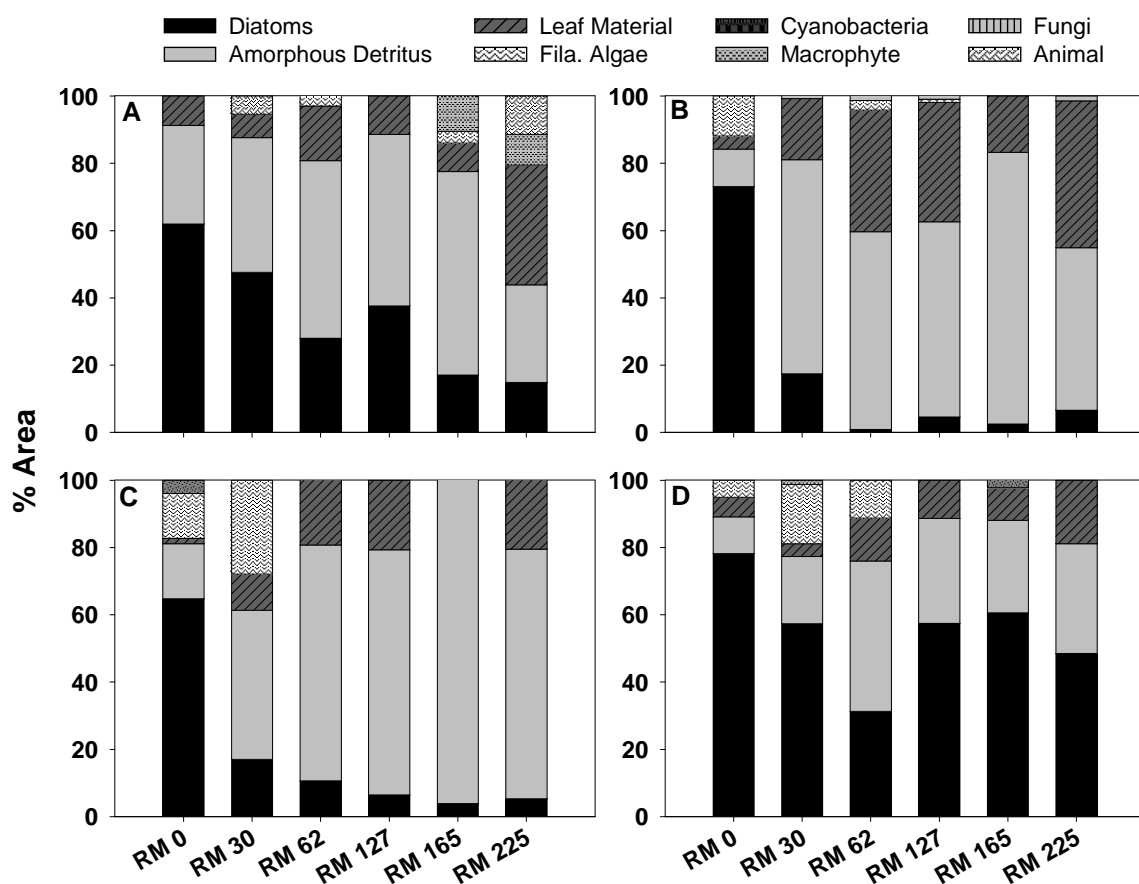


Figure 3. The proportion of particles types comprising suspended organic seston at six sites downstream of dam during A) summer 2006; B) autumn 2006; C) winter 2007; and D) spring 2007.

Table 3. Mean (SE) proportion of particle types comprising suspended organic seston for each site and season.

Season	Food Resource	Site					
		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
Summer	A. Detritus	0.28 (0.01)	0.40 (N/A)	0.53 (N/A)	0.48 (0.08)	0.63 (0.05)	0.49 (0.10)
	Diatoms	0.62 (0.01)	0.48 (N/A)	0.28 (N/A)	0.22 (0.07)	0.15 (0.02)	0.21 (0.05)
	Leaves	0.10 (0.01)	0.07 (N/A)	0.16 (N/A)	0.08 (0.03)	0.11 (0.01)	0.24 (0.06)
	Fila. Algae	0.00	0.00	0.03 (N/A)	0.17 (0.17)	0.01 (0.01)	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.04 (0.03)	0.03 (0.03)
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.05 (N/A)	0.00	0.05 (0.05)	0.06 (0.06)	0.03 (0.04)
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Autumn	A. Detritus	0.11 (0.04)	0.64 (0.02)	0.59 (0.05)	0.58 (0.03)	0.81 (0.03)	0.48 (0.03)
	Diatoms	0.73 (0.10)	0.17 (0.05)	0.01 (0.003)	0.05 (0.02)	0.02 (0.01)	0.07 (0.01)
	Leaves	0.04 (0.03)	0.18 (0.07)	0.36 (0.07)	0.35 (0.03)	0.17 (0.02)	0.44 (0.03)
	Fila. Algae	0.12 (0.07)	0.00	0.00	0.01 (0.01)	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.01 (0.005)	0.04 (0.04)	0.01 (0.005)	0.00	0.01 (0.01)
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Winter	A. Detritus	0.21 (0.02)	0.45 (0.05)	0.58 (0.10)	0.72 (0.02)	0.77 (0.09)	0.72 (0.03)
	Diatoms	0.67 (0.01)	0.21 (0.02)	0.10 (0.01)	0.07 (0.04)	0.03 (0.01)	0.08 (0.01)
	Leaves	0.07 (0.03)	0.18 (0.04)	0.32 (0.10)	0.21 (0.02)	0.20 (0.10)	0.20 (0.03)
	Fila. Algae	0.05 (0.05)	0.16 (0.08)	0.00	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Spring	A. Detritus	0.13 (0.03)	0.18 (0.01)	0.42 (0.02)	0.24 (0.04)	0.40 (0.09)	0.36 (0.03)
	Diatoms	0.81 (0.03)	0.70 (0.06)	0.38 (0.07)	0.60 (0.04)	0.54 (0.08)	0.46 (0.03)
	Leaves	0.04 (0.01)	0.03 (0.01)	0.10 (0.01)	0.16 (0.04)	0.06 (0.02)	0.18 (0.002)
	Fila. Algae	0.02 (0.01)	0.08 (0.04)	0.07 (0.03)	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.01 (0.003)	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.03 (0.03)	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00

Epilithon (rock faces)

Epilithic biofilms in the tailwater reach (RM 0) were dominated by autochthonous resources (diatoms + filamentous algae) during all seasons (Table 4, Appendix 3 and 4).

Along downstream reaches, epilithic biofilms were dominated by allochthonous resources (amorphous detritus + leaf material) during all seasons except during moderate turbidity conditions in summer and spring, when diatoms comprised the greatest proportion of the biofilm for the upper most reach (RM 30) in summer, and the two upper reaches (RM 30 and RM 62) in spring (Table 4, Appendix 3 and 4). Consistent significant differences in the proportion of particle types comprising epilithic biofilms were only present for filamentous algae, with higher proportions of filamentous algae in the tailwaters than downstream sites, during moderate turbidity conditions in the summer and winter (Table 4, Appendix 3 and 4).

Epicremnon (cliff faces)

Epicremnic biofilms in the tailwater reach (RM 0) were dominated by autochthonous resources (diatoms + filamentous algae) during all seasons except during moderate turbidity/low light conditions in winter, when amorphous detritus was the dominant particle type (Table 5, Appendix 5 and 6). Along downstream reaches (RM 30 – RM 225), epicremnic biofilms were dominated by allochthonous resources except during moderate turbidity conditions in summer and spring, when diatoms were the dominant particle type for the upper most reach (RM 30) in the spring, and the two upper reaches (RM 30 and 62) in the summer (Table 5, Appendix 5 and 6).

Table 4. Mean (SE) proportion of particle types comprising epilithon for each site and season.

Season	Food Resource	Site					
		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
Summer	A. Detritus	0.09 (0.02)	0.28 (0.06)	0.58 (0.17)	0.52 (0.17)	0.54 (0.17)	0.79 (0.05)
	Diatoms	0.65 (0.07)	0.58 (0.10)	0.34 (0.13)	0.16 (0.09)	0.32 (0.20)	0.08 (0.03)
	Leaves	0.002 (0.001)	0.11 (0.02)	0.08 (0.04)	0.30 (0.16)	0.14 (0.03)	0.12 (0.05)
	Fila. Algae	0.25 (0.08)	0.001 (0.001)	0.00	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.003 (0.003)	0.03 (0.03)	0.00	0.02 (0.02)	0.00	0.01 (0.01)
	Animal	0.01 (0.01)	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Autumn	A. Detritus	0.11 (0.01)	0.76 (0.02)	0.75 (0.02)	0.84 (0.11)	0.64 (0.05)	0.49 (0.20)
	Diatoms	0.82 (0.04)	0.21 (0.03)	0.24 (0.02)	0.13 (0.11)	0.33 (0.07)	0.37 (0.26)
	Leaves	0.01 (0.01)	0.03 (0.02)	0.01 (0.003)	0.03 (0.01)	0.03 (0.03)	0.14 (0.11)
	Fila. Algae	0.04 (0.04)	0.00	0.00	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.02 (0.01)	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Winter	A. Detritus	0.24 (0.09)	0.53 (0.06)	0.72 (0.05)	0.68 (0.11)	0.56 (0.12)	0.47 (0.23)
	Diatoms	0.62 (0.08)	0.30 (0.04)	0.15 (0.02)	0.07 (0.05)	0.09 (0.05)	0.26 (0.25)
	Leaves	0.04 (0.01)	0.17 (0.05)	0.11 (0.03)	0.24 (0.05)	0.24 (0.06)	0.19 (0.04)
	Fila. Algae	0.10 (0.02)	0.00	0.02 (0.01)	0.00	0.01 (0.01)	0.01 (0.005)
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.001 (0.001)	0.00	0.00	0.01 (0.01)	0.10 (0.10)	0.0002 (0.0002)
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.07 (0.08)
Spring	A. Detritus	0.04 (0.03)	0.29 (0.09)	0.36 (0.03)	0.50 (0.11)	0.49 (0.14)	0.33 (0.02)
	Diatoms	0.62 (0.14)	0.67 (0.08)	0.50 (0.10)	0.44 (0.12)	0.33 (0.15)	0.33 (0.05)
	Leaves	0.01 (0.005)	0.04 (0.004)	0.07 (0.01)	0.06 (0.01)	0.09 (0.05)	0.29 (0.08)
	Fila. Algae	0.25 (0.16)	0.00	0.04 (0.02)	0.00	0.09 (0.09)	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.08 (0.08)	0.00	0.00	0.00	0.00	0.05 (0.05)
	Fungi	0.001 (0.001)	0.00	0.03 (0.03)	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Mean (SE) proportion of particle types comprising epicremnon for each site and season.

Season	Food Resource	Site					
		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
Summer	A. Detritus	0.04 (0.002)	0.18 (0.08)	0.37 (N/A)	0.54 (0.02)	0.49 (0.13)	0.67 (0.05)
	Diatoms	0.78 (0.03)	0.72 (0.13)	0.55 (N/A)	0.11 (0.05)	0.06 (0.06)	0.00
	Leaves	0.01 (0.003)	0.10 (0.05)	0.08 (N/A)	0.29 (0.10)	0.25 (0.06)	0.33 (0.05)
	Fila. Algae	0.17 (0.03)	0.00	0.00	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.06 (0.06)	0.20 (0.20)	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Autumn	A. Detritus	0.25 (0.09)	0.64 (0.04)	0.53 (N/A)	0.79 (0.09)	0.80 (0.103)	0.93 (0.02)
	Diatoms	0.64 (0.06)	0.34 (0.05)	0.43 (N/A)	0.01 (0.01)	0.13 (0.11)	0.02 (0.02)
	Leaves	0.04 (0.01)	0.02 (0.01)	0.04 (N/A)	0.11 (0.07)	0.02 (0.01)	0.05 (0.01)
	Fila. Algae	0.04 (0.04)	0.00	0.00	0.09 (0.09)	0.05 (0.05)	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.03 (0.03)	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Winter	A. Detritus	0.50 (0.15)	0.61 (0.01)	0.74 (0.03)	0.48 (0.10)	0.49 (0.06)	0.57 (0.18)
	Diatoms	0.39 (0.16)	0.07 (0.05)	0.03 (0.01)	0.26 (0.16)	0.22 (0.09)	0.05 (0.03)
	Leaves	0.05 (0.02)	0.32 (0.03)	0.23 (0.02)	0.23 (0.06)	0.26 (0.04)	0.19 (0.04)
	Fila. Algae	0.05 (0.02)	0.00	0.00	0.03 (0.03)	0.03 (0.03)	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.11 (0.11)
	Fungi	0.01 (0.01)	0.00	0.00	0.00	0.00	0.08 (0.08)
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Spring	A. Detritus	0.23 (0.11)	0.30 (0.09)	0.60 (0.09)	0.52 (0.11)	0.70 (0.10)	0.57 (0.11)
	Diatoms	0.68 (0.14)	0.60 (0.15)	0.19 (0.06)	0.22 (0.05)	0.23 (0.06)	0.26 (0.09)
	Leaves	0.01 (0.01)	0.10 (0.06)	0.17 (0.05)	0.20 (0.07)	0.07 (0.03)	0.15 (0.03)
	Fila. Algae	0.08 (0.08)	0.004 (0.004)	0.04 (0.04)	0.04 (0.04)	0.00	0.02 (0.02)
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.002 (0.002)	0.002 (0.002)	0.02 (0.02)	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00

*Macroinvertebrate diets**Simulium arcticum*

S. arcticum consumed mainly diatoms in the tailwater reach during all seasons (Figure 4, Table 6, Appendix 7). Along downstream reaches (RM 30 – RM 225), *S. arcticum* consumed mainly allochthonous resources (amorphous detritus + leaf material) during all seasons (Figure 4, Table 6, Appendix 7). *S. arcticum* diets also changed seasonally, specifically at the sites below major tributaries (RM 30 and RM 62) (Figure 4, Table 6, Appendix 7). During moderate turbidity conditions in the summer, winter, and spring, *S. arcticum* consumed a higher proportion of diatoms (though not always significant) at all downstream sites than during high turbidity conditions in the autumn (Figure 4, Table 6, Appendix 8). In contrast, in the autumn *S. arcticum* consumed mainly amorphous detritus at all downstream sites (Figure 4, Table 6, Appendix 8).

In the tailwaters, autochthonous organic matter (diatoms + filamentous algae + autochthonously derived amorphous detritus) contributes the greatest amount to *S. arcticum* production; contributing 99% to the average yearly (average for all four seasons) *S. arcticum* production (Figure 5). At downstream sites, allochthonous organic matter (allochthonously derived amorphous detritus + leaf material) contributes the greatest amount to *S. arcticum* production; contributing 57% to the average yearly (average for all four seasons and all five downstream sites) *S. arcticum* production (Figure 5). More specifically, in the tailwaters, diatoms contribute the greatest amount to *S. arcticum* production during all seasons (85%-95%, range for all seasons) (Table 7). At downstream sites, allochthonous amorphous detritus contributes the greatest amount to *S.*

arcticum production during high turbidity conditions in the autumn (65-93%, range for the five downstream sites). During moderate turbidity conditions in the summer, winter, and spring, diatoms and allochthonous amorphous detritus contribute somewhat equally to production (Table 7). During these seasons diatoms can contribute from 27-67% (range for the five downstream sites, during the three moderate turbidity seasons), and allochthonous amorphous detritus can contribute from 22-64% (range for the five downstream sites during the three moderate turbidity seasons) to *S. arcticum* production.

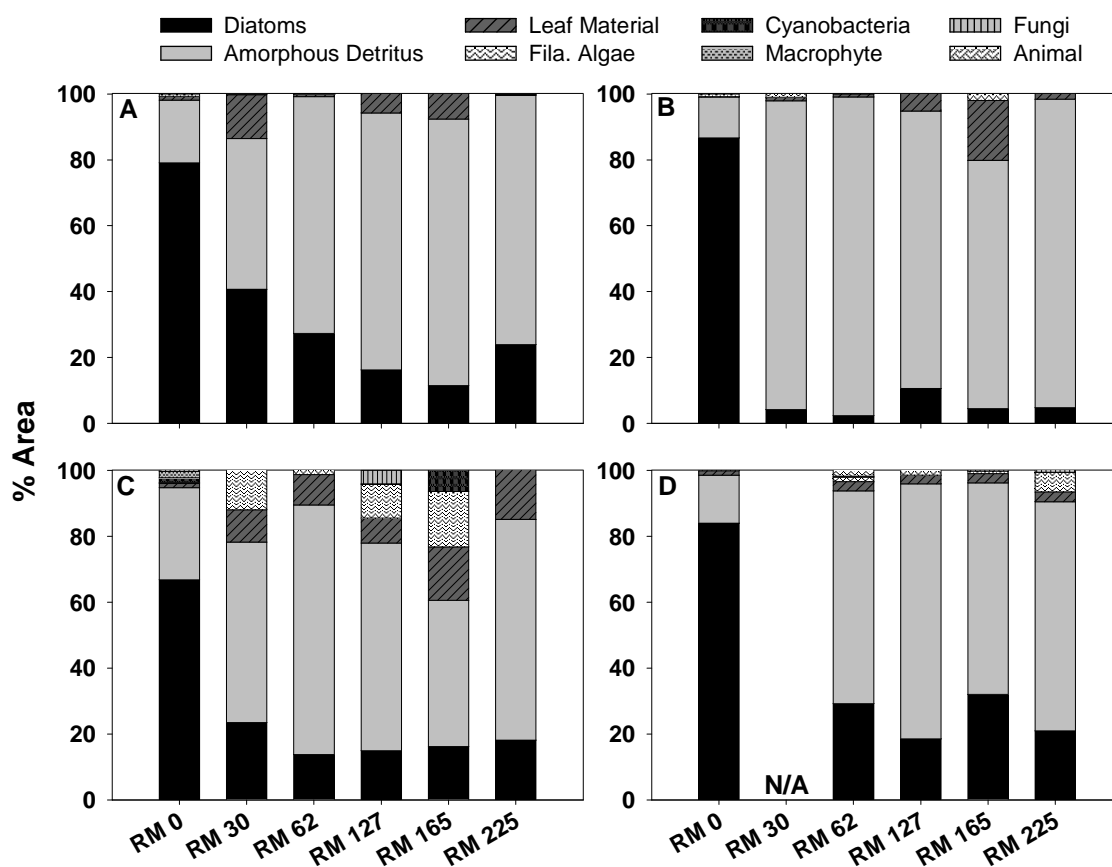


Figure 4. The proportion of particle types consumed seasonally by *Simulium arcticum* at six sites downstream of dam during A) summer 2006; B) autumn 2006; C) winter 2007; and D) spring 2007.

Table 6. Mean (SE) proportion of consumption by *Simulium arcticum* for each site and season. N/A indicates no data available.

Season	Food Resource	Site					
		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
Summer	A. Detritus	0.19 (0.03)	0.46 (0.04)	0.72 (0.03)	0.78 (0.02)	0.81 (0.03)	0.76 (0.04)
	Diatoms	0.79 (0.03)	0.41 (0.05)	0.27 (0.03)	0.16 (0.03)	0.12 (0.01)	0.24 (0.04)
	Leaves	0.01 (0.01)	0.13 (0.08)	0.01 (0.004)	0.06 (0.01)	0.07 (0.03)	0.002 (0.002)
	Fila. Algae	0.01 (0.01)	0.00	0.001 (0.001)	0.00	0.00	0.00
	Cyanobacteria	0.001(0.0004)	0.003 (0.001)	0.00	0.00	0.00	0.002 (0.002)
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Autumn	A. Detritus	0.12 (0.03)	0.94 (0.02)	0.97 (0.02)	0.87 (0.04)	0.75 (0.8)	0.94 (0.004)
	Diatoms	0.87 (0.03)	0.04 (0.01)	0.02 (0.02)	0.09 (0.05)	0.05 (0.02)	0.05 (0.01)
	Leaves	0.001 (0.004)	0.01 (0.005)	0.01 (0.004)	0.04 (0.02)	0.18 (0.10)	0.01 (0.01)
	Fila. Algae	0.01 (0.004)	0.01 (0.01)	0.00	0.00	0.02 (0.02)	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Winter	A. Detritus	0.28 (0.06)	0.55 (0.14)	0.76 (0.04)	0.63 (0.13)	0.44 (0.04)	0.67 (0.05)
	Diatoms	0.67 (0.06)	0.23 (0.11)	0.14 (0.02)	0.15 (0.06)	0.16 (0.04)	0.18 (0.04)
	Leaves	0.01 (0.01)	0.10 (0.03)	0.09 (0.03)	0.08 (0.02)	0.15 (0.06)	0.15 (0.02)
	Fila. Algae	0.004 (0.003)	0.12 (0.12)	0.01 (0.01)	0.10 (0.10)	0.17 (0.07)	0.00
	Cyanobacteria	0.01 (0.01)	0.00	0.00	0.00	0.07 (0.07)	0.00
	Macrophyte	0.02 (0.01)	0.00	0.00	0.001 (0.002)	0.00	0.00
	Fungi	0.003 (0.003)	0.00	0.00	0.04 (0.02)	0.01 (0.005)	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Spring	A. Detritus	0.15 (0.03)	N/A	0.65 (0.02)	0.77 (N/A)	0.64 (0.06)	0.69 (0.07)
	Diatoms	0.84 (0.03)	N/A	0.29 (0.03)	0.19 (N/A)	0.32 (0.06)	0.21 (0.03)
	Leaves	0.01 (0.002)	N/A	0.03 (0.01)	0.03 (N/A)	0.03 (0.01)	0.03 (0.01)
	Fila. Algae	0.00	N/A	0.01 (0.01)	0.01 (N/A)	0.01 (0.01)	0.06 (0.06)
	Cyanobacteria	0.00	N/A	0.00	0.00	0.00	0.00
	Macrophyte	0.00	N/A	0.003 (0.003)	0.00	0.00	0.00
	Fungi	0.001 (0.001)	N/A	0.00	0.00	0.002 (0.001)	0.01 (0.002)
	Animal	0.00	N/A	0.02 (0.01)	0.00	0.00	0.00
	Red Algae	0.00	N/A	0.00	0.00	0.00	0.00

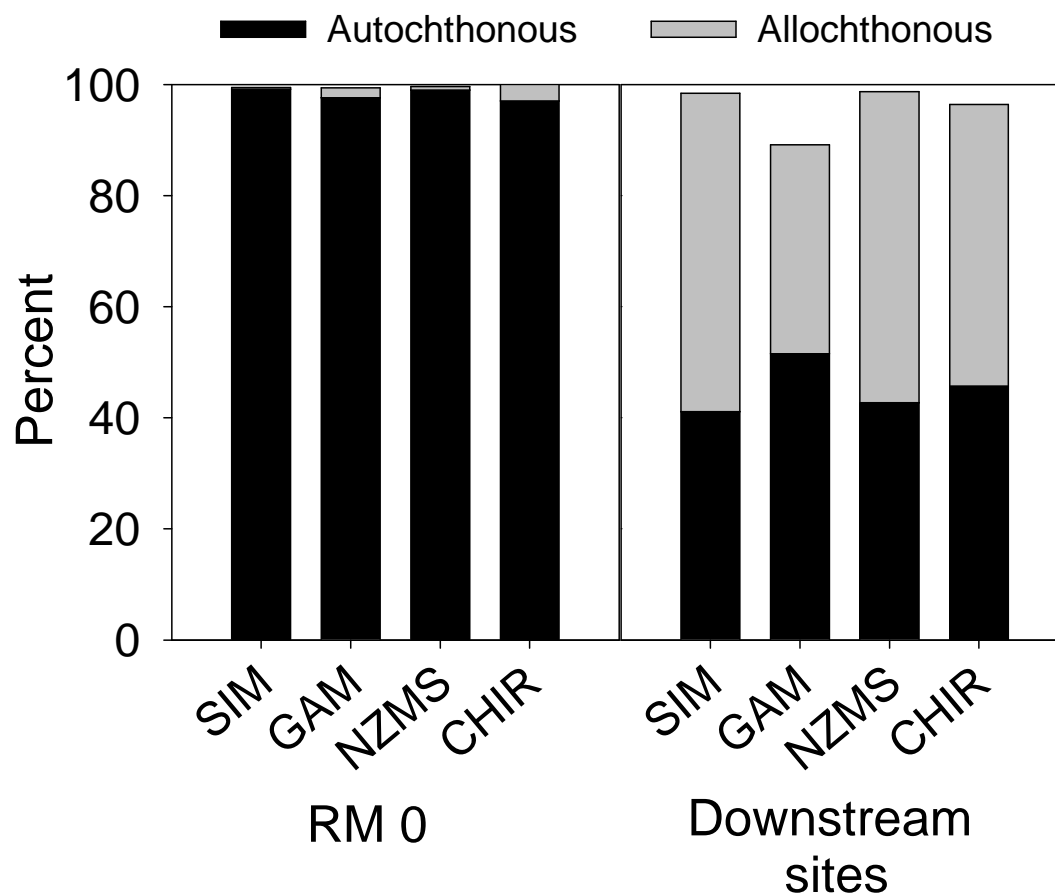


Figure 5. The percent of each taxon's production attributable to autochthonous (diatoms + filamentous algae + autochthonously derived amorphous detritus) and allochthonous (leaf material + allochthonously derived amorphous detritus) resources in the tailwaters (RM 0) and at downstream sites. The percent of production attributable to autochthonous and allochthonous resources was calculated seasonally at each site. Seasonal calculations were averaged to estimate the yearly average percent attributable to resources for each taxon. Seasonal calculations for the five downstream sites were also averaged to estimate the yearly average percent attributable to resources for the downstream system.

Table 7. Production attributed to food type (%). Calculation: Food type in gut (%) x Assimilation efficiency (AE) x Net production efficiency (NPE)/ Σ (G(a+b+c...n) \times AE \times NPE). N/A indicates no data available.

Season	Taxa	Food Resource	Site					
Summer	Simuliid		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
		Allochthonous						
		A. Detritus	0	22	44	57	63	49
		Autochthonous						
		A. Detritus	7	3	2	2	1	2
		Diatoms	91	67	52	36	29	49
		Leaves	0	7	1	5	6	0.1
		Fila. Algae	1	0	0.2	0	0	0
		Cyanobacteria	0.04	0.2	0	0	0	0.1
		Macrophyte	0	0	0	0	0	0
		Fungi	0	0	0	0	0	0
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0
Autumn	Simuliid	Allochthonous						
		A. Detritus	0	85	93	73	65	84
		Autochthonous						
		A. Detritus	4	1	0.3	1	1	1
		Diatoms	95	10	6	23	13	14
		Leaves	0.04	1	1	3	16	2
		Fila. Algae	1	3	0	0	5	0
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	0	0	0	0	0
		Fungi	0	0	0	0	0	0
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0
Winter	Simuliid	Allochthonous						
		A. Detritus	0	27	54	34	22	44
		Autochthonous						
		A. Detritus	12	5	4	3	4	5
		Diatoms	85	41	32	27	28	40
		Leaves	0.4	6	7	5	9	11
		Fila. Algae	0.4	21	2	18	30	0
		Cyanobacteria	0.4	0	0	0	4	0
		Macrophyte	1	0	0	0.1	0	0
		Fungi	1	0	0	12	3	0
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0

Table 7. Continued.

Season	Taxa	Food Resource	Site					
Spring	Simuliid		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
		Allochthonous						
		A. Detritus	0	N/A	37	54	37	43
		Autochthonous						
		A. Detritus	6	N/A	1	1	1	1
		Diatoms	94	N/A	50	41	57	40
		Leaves	0.4	N/A	2	2	2	2
		Fila. Algae	0	N/A	2	2	2	11
		Cyanobacteria	0	N/A	0	0	0	0
		Macrophyte	0	N/A	0.2	0	0	0
		Fungi	0.2	N/A	0	0	1	3
		Animal	0	N/A	8	0	0	0
		Red Algae	0	N/A	0	0	0	0
Summer	<i>Gammarus</i>	Allochthonous						
		A. Detritus	0	26	52	11	N/A	46
		Autochthonous						
		A. Detritus	27	3	2	4	N/A	2
		Diatoms	71	64	35	83	N/A	50
		Leaves	2	3	12	2	N/A	1
		Fila. Algae	0	3	0.2	0	N/A	0
		Cyanobacteria	0	0	0	0	N/A	0
		Macrophyte	0	0	0	0	N/A	0
		Fungi	0	0	0	0	N/A	0
		Animal	0	0	0	0	N/A	0
		Red Algae	0	0	0	0	N/A	0
Autumn	<i>Gammarus</i>	Allochthonous						
		A. Detritus	0	45	69	33	31	79
		Autochthonous						
		A. Detritus	18	2	0	0	1	0.3
		Diatoms	64	38	3	5	15	5
		Leaves	1	9	10	6	10	6
		Fila. Algae	18	6	8	3	5	8
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	0	5	4	3	0
		Fungi	0	0	5	22	20	0.5
		Animal	0	0	0	27	16	0
		Red Algae	0	0	0	0	0	0

Table 7. Continued.

Season	Taxa	Food Resource	Site					
Winter	<i>Gammarus</i>		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
		Allochthonous						
		A. Detritus	0	39	27	6	31	37
		Autochthonous						
		A. Detritus	12	3	5	3	4	4
		Diatoms	73	27	38	26	29	29
		Leaves	3	2	5	1	3	5
		Fila. Algae	11	14	24	62	29	21
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	2	1	0	0	0	1
		Fungi	0	6	0	2	0	3
		Animal	0	8	1	0	4	0
		Red Algae	0	0	0	0	0	0
Spring	<i>Gammarus</i>	Allochthonous						
		A. Detritus	0	13	14	28	27	16
		Autochthonous						
		A. Detritus	23	2	2	2	0.2	1
		Diatoms	75	84	82	67	10	60
		Leaves	2	1	2	3	2	3
		Fila. Algae	0	0	0	0	0	0
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	0	0	0	0	0
		Fungi	0	0	0	0	0	0
		Animal	0	0	0	1	61	21
		Red Algae	0	0	0	0	0	0
Summer	NZMS	Allochthonous						
		A. Detritus	0	31	77	29	N/A	15
		Autochthonous						
		A. Detritus	20	3	1	3	N/A	4
		Diatoms	72	57	18	53	N/A	79
		Leaves	0	9	4	16	N/A	2
		Fila. Algae	8	0	0	0	N/A	0
		Cyanobacteria	0	0	0	0	N/A	0
		Macrophyte	0	0	0	0	N/A	0
		Fungi	0	0	0	0	N/A	0
		Animal	0	0	0	0	N/A	0
		Red Algae	0	0	0	0	N/A	0

Table 7. Continued.

Season	Taxa	Food Resource	Site					
Autumn	NZMS		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
		Allochthonous						
		A. Detritus	0	54	61	52	41	74
		Autochthonous						
		A. Detritus	18	2	1	2	2	1
		Diatoms	81	40	26	39	42	20
		Leaves	1	4	6	4	4	3
		Fila. Algae	1	0	1	0	4	0
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	0	0	0	1	0
		Fungi	0	0	4	4	6	1
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0
Winter	NZMS	Allochthonous						
		A. Detritus	0	27	N/A	69	45	21
		Autochthonous						
		A. Detritus	13	7	N/A	1	4	7
		Diatoms	83	52	N/A	8	35	52
		Leaves	0.4	14	N/A	17	16	19
		Fila. Algae	3	0	N/A	0	0	0
		Cyanobacteria	0	0	N/A	0	0	0
		Macrophyte	1	0	N/A	0	0	0
		Fungi	0	0.3	N/A	5	0	2
		Animal	0	0	N/A	0	0	0
		Red Algae	0	0	N/A	0	0	0
Spring	NZMS	Allochthonous						
		A. Detritus	0	56	64	50	25	56
		Autochthonous						
		A. Detritus	14	1	1	1	11	1
		Diatoms	84	40	31	44	47	26
		Leaves	1	3	3	5	17	11
		Fila. Algae	0	0	0	0	0	7
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	0	1	0	0	0
		Fungi	0	0	0	0	0	0
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0

Table 7. Continued.

Season	Taxa	Food Resource	Site					
Summer	Chironomid		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
		Allochthonous						
		A. Detritus	0	17	39	50	26	36
		Autochthonous						
		A. Detritus	13	3	2	1	3	2
		Diatoms	82	64	44	14	60	43
		Leaves	5	6	15	35	11	18
		Fila. Algae	0	6	0	0	0	0
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	3	0	0	0	0
		Fungi	0	0	0	0	0	1
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0
Autumn	Chironomid	Allochthonous						
		A. Detritus	0	31	44	42	52	48
		Autochthonous						
		A. Detritus	11	3	1	1	0	1
		Diatoms	49	55	27	14	3	26
		Leaves	5	9	28	15	32	20
		Fila. Algae	35	0	0	0	0	0
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	0	0	0	0	0
		Fungi	0	3	0	27	13	4
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0
Winter	Chironomid	Allochthonous						
		A. Detritus	0	50	39	50	30	17
		Autochthonous						
		A. Detritus	3	4	5	4	7	7
		Diatoms	94	31	41	29	54	57
		Leaves	0.4	5	7	16	9	13
		Fila. Algae	2	4	4	0.5	0	0
		Cyanobacteria	0	0	0	0	0	0
		Macrophyte	0	2	0	0	0	0
		Fungi	0	4	3	1	0	6
		Animal	0	0	0	0	0	0
		Red Algae	0	0	0	0	0	0

Table 7. Continued.

Season	Taxa	Food Resource	Site					
Spring	Chironomid		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
		Allochthonous						
		A. Detritus	0	N/A	26	20	22	55
		Autochthonous						
		A. Detritus	3	N/A	2	2	2	1
		Diatoms	94	N/A	66	70	73	31
		Leaves	0.4	N/A	5	5	4	13
		Fila. Algae	2	N/A	0	5	0	0
		Cyanobacteria	0.1	N/A	0	0	0	0
		Macrophyte	0	N/A	0	0	0	0
		Fungi	0	N/A	1	0	0	0
		Animal	0	N/A	0	0	0	0
		Red Algae	0	N/A	0	0	0	0

Gammarus lacustris

In general, *G. lacustris* consumed similar proportions of diatoms and amorphous detritus in the tailwater reach during all seasons (Table 8, Appendix 9). Along downstream reaches (RM 30 – RM 225), *G. lacustris* generally consumed higher proportions of allochthonous resources (though not always significant) than in the tailwaters in all seasons, except during moderate turbidity/light conditions in the spring, when they consumed a higher proportion of allochthonous resources at only two of the five downstream sites, and consumed more diatoms than allochthonous resources at three of the five downstream sites (Table 8, Appendix 9). *G. lacustris* diets also changed seasonally. During moderate turbidity conditions in the summer, winter, and spring, *G. lacustris* generally consumed a higher proportion of diatoms (though not always significant) at downstream sites than during high turbidity conditions in the autumn (Table 8, Appendix 10). *G. lacustris* also generally consumed a higher proportion of diatoms at downstream sites (though not always significant) during moderate turbidity

and moderate/high light conditions, which occur in spring and summer, compared to the moderate turbidity/low light conditions in the winter (Table 8, Appendix 10).

In the tailwaters, autochthonous organic matter (diatoms + filamentous algae + autochthonously derived amorphous detritus) contributes the greatest amount to *G. lacustris* production; contributing 97% to the yearly average (average for all four seasons) *G. lacustris* production (Figure 5). At downstream sites, autochthonous organic matter contributes 52% to the average yearly (average for all four seasons and all five downstream sites) *G. lacustris* production (Figure 5). Specifically, in the tailwaters, diatoms contribute the greatest amount to their production during all seasons (63%-75%, range for all seasons) (Table 7). In contrast, at downstream sites, during high turbidity conditions in autumn, allochthonous amorphous detritus contributes the greatest amount to *G. lacustris* production (31-79%, range for the five downstream sites). During moderate turbidity conditions in the summer, winter, and spring, diatoms generally contribute more to production than allochthonous amorphous detritus (Table 7). During these seasons diatoms can contribute from 10-84% (range for the five downstream sites, during the three moderate turbidity seasons), and allochthonous amorphous detritus can contribute from 6-52% (range for the five downstream sites, during the three moderate turbidity seasons) to *G. lacustris* production.

Table 8. Mean (SE) proportion of consumption by *Gammarus lacustris* for each site and season. N/A indicates no data available.

Season	Food Resource	Site					
		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
Summer	A. Detritus	0.52 (0.05)	0.53 (0.18)	0.70 (0.17)	0.34 (N/A)	N/A	0.73 (0.13)
	Diatoms	0.45 (0.04)	0.39 (0.19)	0.15 (0.03)	0.62 (N/A)	N/A	0.25 (0.15)
	Leaves	0.03 (0.02)	0.06 (0.05)	0.15 (0.15)	0.04 (N/A)	N/A	0.02 (0.02)
	Fila. Algae	0.00	0.02 (0.02)	0.001 (0.001)	0.00	N/A	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	N/A	0.00
	Macrophyte	0.00	0.00	0.00	0.00	N/A	0.00
	Fungi	0.00	0.00	0.00	0.00	N/A	0.00
	Animal	0.00	0.00	0.00	0.00	N/A	0.00
	Red Algae	0.00	0.00	0.00	0.00	N/A	0.00
Autumn	A. Detritus	0.38 (0.10)	0.66 (0.03)	0.77 (0.08)	0.61 (0.10)	0.56 (0.05)	0.88 (0.03)
	Diatoms	0.46 (0.06)	0.18 (0.02)	0.01 (0.01)	0.03 (0.01)	0.09 (0.03)	0.02 (0.01)
	Leaves	0.02 (0.01)	0.13 (0.02)	0.11 (0.04)	0.11 (0.01)	0.17 (0.01)	0.07 (0.02)
	Fila. Algae	0.14 (0.05)	0.03 (0.03)	0.03 (0.02)	0.03 (0.01)	0.03 (0.02)	0.03 (0.03)
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.06 (0.06)	0.07 (0.06)	0.05 (0.03)	0.00
	Fungi	0.00	0.00	0.02 (0.01)	0.08 (0.04)	0.07 (0.02)	0.001 (0.001)
	Animal	0.00	0.00	0.00	0.07 (0.07)	0.03 (0.03)	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Winter	A. Detritus	0.27 (0.10)	0.70 (0.09)	0.55 (0.16)	0.23 (0.06)	0.60 (0.11)	0.63 (0.08)
	Diatoms	0.55 (0.10)	0.15 (0.05)	0.22 (0.05)	0.21 (0.12)	0.17 (0.04)	0.15 (0.04)
	Leaves	0.06 (0.01)	0.02 (0.01)	0.09 (0.03)	0.02 (0.01)	0.05 (0.04)	0.07 (0.02)
	Fila. Algae	0.08 (0.05)	0.08 (0.08)	0.14 (0.13)	0.53 (0.06)	0.17 (0.13)	0.11 (0.05)
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.04 (0.02)	0.01 (0.01)	0.00	0.00	0.00	0.02 (0.01)
	Fungi	0.00	0.02 (0.02)	0.00	0.01 (0.01)	0.00	0.01 (0.01)
	Animal	0.00	0.02 (0.02)	0.003 (0.003)	0.00	0.01 (0.01)	0.01 (0.01)
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Spring	A. Detritus	0.47 (0.11)	0.34 (0.08)	0.36 (0.06)	0.54 (0.14)	0.67 (0.19)	0.40 (0.01)
	Diatoms	0.50 (0.13)	0.63 (0.08)	0.60 (0.06)	0.41 (0.13)	0.08 (0.02)	0.47 (0.05)
	Leaves	0.03 (0.02)	0.03 (0.01)	0.04 (0.01)	0.05 (0.02)	0.04 (0.004)	0.06 (0.04)
	Fila. Algae	0.00	0.00	0.00	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.003 (0.003)	0.21 (0.21)	0.07 (0.07)
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00

Potamopyrgus antipodarum (NZMS)

NZMS consumed mainly autochthonous resources (diatoms + filamentous algae)

in the tailwater reach during all seasons (Table 9, Appendix 11). Along downstream

reaches (RM 30 – RM 225), NZMS consumed mainly allochthonous resources

(amorphous detritus + leaf material) during all seasons (Table 9, Appendix 11). Within sites there were no consistent seasonal changes in NZMS diets among seasons (Table 9, Appendix 12), except during moderate turbidity/high light conditions in summer, when NZMS generally consumed higher proportions of diatoms (though not significant) at downstream sites.

In the tailwaters, autochthonous organic matter (diatoms + filamentous algae + autochthonously derived amorphous detritus) contributes the greatest amount to NZMS production; contributing 98% to the average yearly (average for all four seasons) NZMS production (Figure 5). At downstream sites, allochthonous organic matter (allochthonously derived amorphous detritus + leaf material) contributes 55% to the average yearly (average for all four seasons and all five downstream sites) NZMS production (Figure 5). Specifically, in the tailwaters, diatoms contribute the greatest amount to NZMS production during all seasons (72%-84%, range for all seasons) (Table 7). In contrast, at downstream sites, during high turbidity conditions in autumn, allochthonous amorphous detritus contributes the greatest amount to NZMS production (41-74%, range for the five downstream sites). During moderate turbidity conditions in the summer, winter, and spring, diatoms and allochthonous amorphous detritus contribute somewhat equally to production (Table 7). During these seasons diatoms can contribute from 18-79% (range for the five downstream sites, during the three moderate turbidity seasons), and allochthonous amorphous detritus can contribute from 15-77% (range for the five downstream sites, during the three moderate turbidity seasons) to NZMS production.

Table 9. Mean (SE) proportion of consumption by *Potamopyrgus antipodarum* (NZMS) for each site and season. N/A indicates no data available.

Season	Food Resource	Site					
		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
Summer	A. Detritus	0.42 (0.07)	0.55 (0.05)	0.89 (N/A)	0.49 (0.04)	N/A	0.40 (0.13)
	Diatoms	0.51 (0.10)	0.30 (0.09)	0.07 (N/A)	0.27 (0.06)	N/A	0.56 (0.13)
	Leaves	0.00	0.15 (0.05)	0.04 (N/A)	0.24 (0.07)	N/A	0.04 (0.04)
	Fila. Algae	0.07 (0.06)	0.00	0.00	0.00	N/A	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	N/A	0.00
	Macrophyte	0.00	0.00	0.00	0.00	N/A	0.00
	Fungi	0.00	0.00	0.00	0.00	N/A	0.00
	Animal	0.00	0.00	0.00	0.00	N/A	0.00
	Red Algae	0.00	0.00	0.00	0.00	N/A	0.00
Autumn	A. Detritus	0.39 (0.02)	0.76 (0.04)	0.79 (0.04)	0.76 (0.03)	0.68 (0.05)	0.88 (0.01)
	Diatoms	0.59 (0.02)	0.18 (0.04)	0.11 (0.03)	0.18 (0.03)	0.22 (0.06)	0.08 (0.02)
	Leaves	0.02 (0.005)	0.06 (0.02)	0.08 (0.01)	0.05 (0.01)	0.07 (0.01)	0.04 (0.01)
	Fila. Algae	0.003 (0.004)	0.00	0.01 (0.004)	0.00	0.01 (0.01)	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.01 (0.01)	0.00
	Fungi	0.00	0.00	0.01 (0.01)	0.01 (0.002)	0.01 (0.003)	0.003 (0.003)
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Winter	A. Detritus	0.30 (0.11)	0.52 (0.03)	N/A	0.77 (0.05)	0.64 (0.03)	0.43 (0.10)
	Diatoms	0.65 (0.10)	0.27 (0.05)	N/A	0.03 (0.01)	0.15 (0.02)	0.27 (0.14)
	Leaves	0.01 (0.002)	0.21 (0.03)	N/A	0.19 (0.04)	0.21 (0.04)	0.29 (0.04)
	Fila. Algae	0.01 (0.01)	0.00	N/A	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	N/A	0.00	0.00	0.00
	Macrophyte	0.03 (0.02)	0.00	N/A	0.00	0.00	0.00
	Fungi	0.00	0.001 (0.001)	N/A	0.01 (0.01)	0.00	0.01 (0.005)
	Animal	0.00	0.00	N/A	0.00	0.00	0.00
	Red Algae	0.00	0.00	N/A	0.00	0.00	0.00
Spring	A. Detritus	0.33 (0.08)	0.78 (0.03)	0.82 (0.05)	0.72 (0.03)	0.77 (0.07)	0.72 (0.11)
	Diatoms	0.64 (0.08)	0.18 (0.04)	0.13 (0.05)	0.21 (0.04)	0.11 (0.04)	0.11 (0.05)
	Leaves	0.03 (0.01)	0.04 (0.01)	0.04 (0.01)	0.07 (0.03)	0.12 (0.04)	0.14 (0.07)
	Fila. Algae	0.00	0.00	0.00	0.00	0.00	0.03 (0.03)
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.01 (0.01)	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.00
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00

Chironomidae

Chironomids predominately consumed autochthonous resources (diatoms + filamentous algae) in the tailwater reach (RM 0) during all seasons (Table 10, Appendix 13). Along downstream reaches (RM 30 – RM 225), chironomids consumed mainly

allochthonous resources (amorphous detritus + leaf material) during all seasons except spring, when diatoms and allochthonous resources were consumed in similar proportions (Table 10, Appendix 13). Within downstream sites, chironomids changed their diets with season and generally consumed higher proportions of diatoms (though not significant) during moderate turbidity conditions in summer, winter, and spring, than during high turbidity conditions in the autumn (Table 10, Appendix 14). Also during autumn chironomids consumed a higher proportion of filamentous algae at RM 0, with filamentous algae comprising 27% of their diets.

In the tailwaters, autochthonous organic matter (diatoms + filamentous algae + autochthonously derived amorphous detritus) contributes the greatest amount to chironomid production; contributing 97% to the average yearly (average for all four seasons) chironomid production (Figure 5). In contrast, at downstream sites, allochthonous organic matter (allochthonously derived amorphous detritus + leaf material) contributes 50% to the average yearly (average for all four seasons and all five downstream sites) chironomid production (Figure 5). Specifically, in the tailwaters, diatoms contribute the greatest amount to chironomid production during all seasons (49%-94%, range for all seasons) (Table 7). At downstream sites, during high turbidity conditions in autumn, allochthonous amorphous detritus contributes the greatest amount to chironomid production at all downstream sites (43-59%, range for downstream sites, RM 62 – RM 265) except RM 30, where diatoms still contribute the most to production (54%) (Table 7). During moderate turbidity conditions in the summer, winter, and spring, diatoms contribute the greatest amount to production at most sites (Table 7). During these

seasons diatoms can contribute from 14-73% (range for the five downstream sites, during the three moderate turbidity seasons), and allochthonous amorphous detritus can contribute from 17-55% (range for the five downstream sites, during the three moderate turbidity seasons) to chironomid production.

Table 10. Mean (SE) proportion of consumption by Chironomidae for each site and season. N/A indicates no data available.

Season	Food Resource	Site					
		RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
Summer	A. Detritus	0.29 (0.02)	0.37 (0.11)	0.58 (0.03)	0.56 (0.05)	0.48 (0.10)	0.53 (0.14)
	Diatoms	0.60 (0.07)	0.40 (0.06)	0.21 (0.04)	0.05 (0.03)	0.33 (0.14)	0.20 (0.11)
	Leaves	0.11 (0.05)	0.13 (0.02)	0.21 (0.04)	0.39 (0.08)	0.19 (0.07)	0.26 (0.07)
	Fila. Algae	0.00	0.04 (0.04)	0.00	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.06 (0.06)	0.00	0.00	0.00	0.00
	Fungi	0.00	0.00	0.00	0.00	0.00	0.004 (0.004)
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Autumn	A. Detritus	0.25 (0.002)	0.55 (0.03)	0.55 (0.05)	0.63 (0.08)	0.59 (0.13)	0.62 (0.05)
	Diatoms	0.38 (0.04)	0.30 (0.06)	0.11 (0.05)	0.07 (0.02)	0.01 (0.01)	0.11 (0.05)
	Leaves	0.11 (0.06)	0.14 (0.07)	0.34 (0.10)	0.22 (0.04)	0.37 (0.15)	0.26 (0.08)
	Fila. Algae	0.26 (0.02)	0.00	0.00	0.00	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.00	0.00	0.00	0.00	0.00
	Fungi	0.00	0.01 (0.01)	0.00	0.08 (0.03)	0.03 (0.01)	0.01 (0.01)
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Winter	A. Detritus	0.09 (0.03)	0.73 (0.07)	0.66 (0.03)	0.67 (0.02)	0.58 (0.04)	0.43 (0.04)
	Diatoms	0.88 (0.03)	0.14 (0.06)	0.20 (0.04)	0.12 (0.02)	0.28 (0.06)	0.33 (0.07)
	Leaves	0.01 (0.003)	0.07 (0.03)	0.11 (0.04)	0.20 (0.02)	0.14 (0.05)	0.22 (0.04)
	Fila. Algae	0.02 (0.02)	0.02 (0.01)	0.02 (0.02)	0.002 (0.002)	0.00	0.00
	Cyanobacteria	0.00	0.00	0.00	0.00	0.00	0.00
	Macrophyte	0.00	0.03 (0.01)	0.00	0.00	0.00	0.00
	Fungi	0.00	0.01 (0.003)	0.01 (0.01)	0.003 (0.003)	0.00	0.02 (0.02)
	Animal	0.00	0.00	0.00	0.00	0.00	0.00
	Red Algae	0.00	0.00	0.00	0.00	0.00	0.00
Spring	A. Detritus	0.09 (0.02)	N/A	0.50 (0.14)	0.42 (0.14)	0.45 (0.03)	0.70 (0.05)
	Diatoms	0.86 (0.02)	N/A	0.40 (0.16)	0.46 (0.19)	0.47 (0.06)	0.13 (0.04)
	Leaves	0.02 (0.01)	N/A	0.10 (0.05)	0.09 (0.02)	0.08 (0.03)	0.17 (0.02)
	Fila. Algae	0.02 (0.02)	N/A	0.00	0.03 (0.03)	0.00	0.00
	Cyanobacteria	0.01 (0.004)	N/A	0.00	0.00	0.00	0.00
	Macrophyte	0.00	N/A	0.00	0.00	0.00	0.00
	Fungi	0.00	N/A	0.004 (0.004)	0.00	0.00	0.00
	Animal	0.00	N/A	0.00	0.00	0.00	0.00
	Red Algae	0.00	N/A	0.00	0.00	0.00	0.00

Relative contribution of autochthonous and allochthonous resources to the macroinvertebrate community

Macroinvertebrate production in the Grand Canyon is supported by autochthonous resources in the tailwaters (Figure 5, Table 7). In contrast, at downstream sites, macroinvertebrate production is generally supported by a combination of autochthonous and allochthonous resources during moderate turbidity conditions (Table 7), and mainly allochthonous resources during high turbidity conditions. Specifically, during high turbidity conditions allochthonous amorphous detritus contributes the greatest amount to production at downstream sites, and during moderate turbidity conditions diatoms and allochthonous amorphous detritus contribute somewhat equally to production.

Resource consumption relative to resource availability

Resources consumed were generally related to their availability. Composition of the seston, especially the percentage of diatoms and amorphous detritus, was positively related to the diets of *S. arcticum* ($r = 0.866$, $p < 0.001$; $r = 0.610$, $p = 0.002$, respectively, Figure 6); however, other components of the seston were not related to *S. arcticum* diets (Table 11). Epilithic and epicremnic biofilm composition were positively related to each other ($r = 0.853$, $p < 0.001$), so only epilithic biofilms were compared to gut-contents of *G. lacustris*, NZMS and chironomids (Figure 6). Consumption of diatoms and amorphous detritus by these three taxa was positively related to the relative proportion of these resources in the epilithon (Figure 6). In addition, NZMS consumption of leaf material and

filamentous algae was positively related to their relative contribution to biofilm composition ($r = 0.784$, $p < 0.001$; $r = 0.543$, $p = 0.009$, respectively, Table 11).

Table 11. Correlation results examining the relationship between the percent composition of a particle type in the seston or epilithon/rock faces and the percent consumption of the particle type by each taxon.

Food resource	Taxa	Particle Type				
Seston	Simuliid		DIA	AD	LM	FA
		<i>r</i>	0.866	0.610	0.003	0.119
		<i>p</i>	0.000	0.002	0.988	0.590
Epilithon/rock face	<i>Gammarus</i>					
		<i>r</i>	0.587	0.453	-0.283	-0.168
		<i>p</i>	0.003	0.030	0.191	0.443
Epilithon/rock face	NZMS					
		<i>r</i>	0.513	0.493	0.784	0.543
		<i>p</i>	0.015	0.020	0.000	0.009
Epilithon/rock face	Chironomid					
		<i>r</i>	0.677	0.734	0.287	0.051
		<i>p</i>	0.000	0.000	0.185	0.819

r = Pearson product-moment correlation coefficient and associated *p* -value.

Discussion

As predicted, macroinvertebrate diets tracked downstream changes in resource availability in the Colorado River, and autochthonous carbon was consumed in greater proportions in the tailwaters and more allochthonous carbon was consumed downstream. Consumption of allochthonous resources and the contribution of allochthonous resources to macroinvertebrate production was most important during the monsoon season when there is high turbidity and tributaries can contribute up to 500,000 metric tons of particulate organic matter to the mainstem of the Colorado River (ca. 50 times the amount of algal production) (Kennedy et al. unpublished data). This work demonstrates that macroinvertebrates consume some of this tributary allochthonous carbon and this material supports higher trophic levels in the Colorado River.

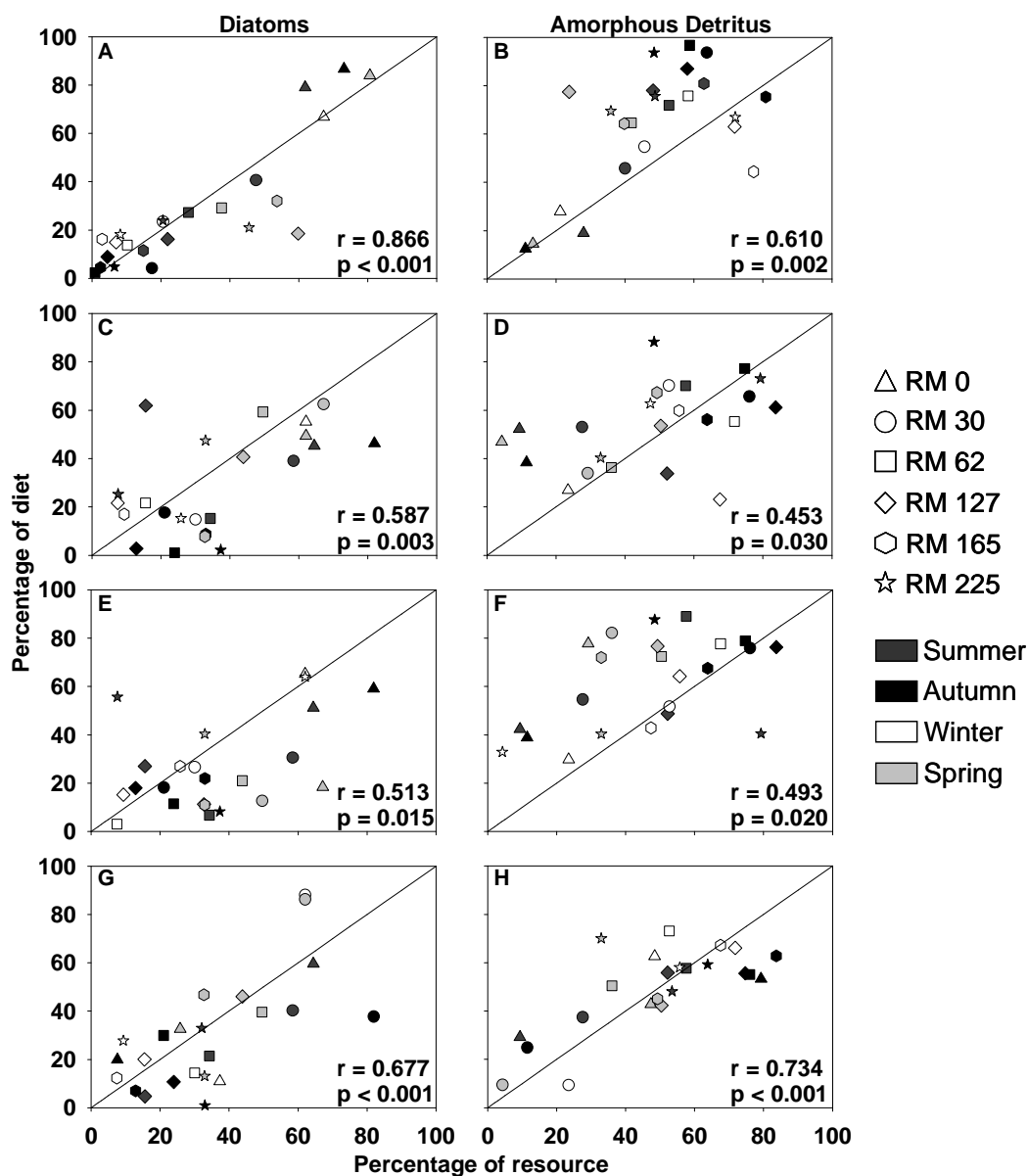


Figure 6. Correlation analysis of the average percent particle type (diatoms or amorphous detritus) comprising an available food resource (seston or epilithon) versus the average percent of the diet the particle comprises, at each site, during each season. A, B) Seston vs. *S. arcticum*; C, D) epilithon vs. *G. lacustris*; E, F) epilithon vs. NZMS; G, H) epilithon vs. chironomids. Pearson product-moment correlation coefficients (r) and associated p -values are given. Line represents the line of equity (one-to-one relationship). Points above the line demonstrate that the percent of the particle type consumed by the macroinvertebrate is greater than the percent composition of the particle type in the food resource. Points below the line demonstrate that the percent of the particle type consumed by the macroinvertebrate is less than the percent composition of the particle type in the food resource.

Seston

Composition of the seston displayed the strongest patterns among resources in spatial and seasonal shifts in composition and shifted most drastically between the tailwaters (RM 0) and downstream sites (RM 30 – RM 225) during high turbidity and low light conditions. The flooding of two major tributaries, the Paria River (RM 1.0) and the Little Colorado River (RM 61) contribute the largest amounts of suspended sediment and organic matter to the mainstem and consequently amorphous detritus and leaf material dominate seston community composition downstream of these tributaries. Previous analyses of seston from the Paria River using stable isotopes indicate derivation from upland and riparian vegetation, and the isotopic signature was distinct from seston in the mainstem Colorado River tailwaters (Angradi 1994). During seasons when there are significant tributary inputs, amorphous detritus in the seston is most likely allochthonous in origin. During moderate turbidity and high light seasons when there is higher primary production in the tailwaters and downstream, the downstream shift from diatoms to amorphous detritus and leaf material is less drastic. In addition, during these seasons amorphous detritus may be a combination of autochthonously-derived material exported from the tailwaters, and autochthonously- and allochthonously-derived material from tributaries. The Paria River is generally turbid, but many smaller tributaries are clear and may contribute both autochthonous and allochthonous material to the mainstem.

Epilithic biofilms

Although, autochthonous resources dominated the composition of epilithic biofilms in the tailwaters, and allochthonous resources dominated the composition downstream, there were few significant differences in the proportion of particle types in the tailwaters versus downstream sites. Filamentous algae significantly declined at downstream sites during the summer and winter; however, due to high variability among replicates, no significant patterns in the spatial distribution of diatom composition were discerned during any season. Monsoon flooding increases the concentration of suspended sediments and turbidity in the river and reduces water clarity, light levels and gross primary production (Yard et al. 2003), but does not typically scour or disturb the benthos. The reduction of peak discharges due to the Glen Canyon Dam has led to increased substrate stability (Webb et al. 1999, 2005), which allows for significant periphyton development. Diatom communities, particularly late-successional species typical of well-developed periphyton communities, are often adapted to survive in low light conditions (McCormick and Stevenson 1991, Tuji 2000, Sigee 2005) and community composition may not change considerably at downstream sites, even when light levels are reduced. In contrast, the dominant filamentous algae in this system, *Cladophora glomerata* grows best at high light intensities (McMillan and Verduin 1953, Whitton 1967), and the sharp decline in its distribution downstream may be attributed to low light levels. Furthermore, canyon orientation and topographic complexity leads to temporal and spatial solar insolation and may contribute to high variability in epilithic community composition (Yard et al. 2005). Finally, there was often more amorphous detritus and leaf material on

rocks from downstream sites, which may be attributed to settling and deposition of tributary and riparian allochthonous material.

Epicremnic biofilms

Epicremnic biofilms were generally similar to epilithic biofilms. Tailwater epicremnic biofilms were dominated by autochthonous resources during all seasons except winter, and downstream sites were dominated by allochthonous resources at all sites, except during high light and moderate turbidity conditions in the spring and summer, when autochthonous resources were higher. Unlike epilithic biofilms, significant differences in the proportion of particle types in the tailwaters versus downstream sites were more prevalent, particularly during high light conditions in the summer and high turbidity conditions in the autumn. Differences between epilithic and epicremnic biofilms may be due to differences in sampling methods (rocks were grabbed out of rivers and scrubbed in a bucket, cliffs were scrubbed in the river with a scrubbing/sucking device), or different current velocities and depths. Rocks were typically grabbed from high velocity cobble bars and may not retain allochthonous material. Cliff faces are adjacent to deep low-velocity areas, which promotes development of thicker biofilms that may retain more allochthonous material.

Macroinvertebrate diets

Differences among taxa in extent of longitudinal and seasonal diet shifts may be attributed to differences in food acquisition and availability of resources. As expected, resource consumption by *S. arcticum* was highly correlated with seston composition. *S. arcticum* is generally classified as a collector-filterer (Cummins 1973), and comparison

of their diets to seston community composition, confirms the importance of this food resource for these filter-feeding organisms (Wallace and Merritt 1980, Wotton 1984, Parkes et al. 2004). For example, *S. arcticum* consumption generally matched the seasonal and longitudinal shifts occurring in the seston and displayed the greatest shift in diet amongst taxa, shifting diets during all seasons. Site-specific seasonal shifts in *S. arcticum* diets were most prevalent at RM 30 and RM 62 (the sites below the two major tributaries) between the autumn and all other seasons, confirming the effect of tributary floods on resource availability and consumption. Tributary inputs, particularly during the autumn, also contributed significantly more leaf material to the seston than was consumed by *S. arcticum*. Although, simuliids can ingest particles up to 350 μm (Wotton 1976, Wallace and Merritt 1980, Currie and Craig 1987), the majority of studies report ingestion of particles less than 100 μm (Wallace and Merritt 1980). The mismatch between leaf material in the seston and gut contents may be attributed to their inability to filter larger leaf particles from the seston. In addition, larval ingestion rates (Hart and Latta 1986, Hart 1987) and densities (Erman and Chouteau 1979, Hart 1987) have been shown to be positively correlated with food availability. As such, filtering organisms may benefit from increased seston concentrations leading to higher ingestion rates. The success of *S. arcticum* in the Colorado River ecosystem may be due to its ability to effectively access and exploit changing resources.

G. lacustris diets track available resources and their resource consumption was significantly correlated with epilithic resource composition. In contrast to *S. arcticum*, *G. lacustris* only shifted diets to consume more allochthonous resources at downstream sites

during three of the four seasons, and during spring consumed a higher proportion of autochthonous resources at most of the downstream sites. Also at downstream sites during moderate turbidity and moderate/high light conditions in the spring and summer, *G. lacustris* consumed higher proportions of diatoms than in the autumn and winter. *G. lacustris* are classified as facultative shredders (Cummins and Klug 1979) and because of their ability to move upstream by swimming and crawling along substrates (Hughes 1970); they are not constrained to feeding in one habitat. The epilithon of the tailwaters of Glen Canyon Dam is dominated by *Cladophora glomerata* and this is the preferred habitat of *G. lacustris* (Shannon et al. 1994) and epiphytic diatoms are their preferred food resource (Pinney 1991). *G. lacustris* are also common on cliff faces, especially when *Cladophora glomerata* cover is low in winter and spring (personal observation). Downstream, *G. lacustris* is found on cliff faces; root wads associated with undercut banks; macrophytes and bryophytes; reeds and sedges such as *Phragmites australis* and *Carex aquatilis*; and rarely on cobble bars (personal observation). *G. lacustris* may be able to utilize a variety of habitats to selectively feed on preferred resources (Bärlocher 1985, Arsuffi and Suberkropp 1989, Friberg and Jacobsen 1994), which may explain their higher consumption of autochthonous resources at downstream sites during some seasons. Specifically, in this system *G. lacustris* selectively feeds on epiphytic diatoms (Pinney 1991).

My results show *G. lacustris* feeds on more amorphous detritus than previously reported. In the tailwaters, this amorphous detritus is most likely autochthonously derived because of the lack of upstream allochthonous inputs. In addition, amorphous detritus

may be derived from algal exudates (or algal exopolymer secretions) (Hart and Lovvorn 2003) and may be ingested while feeding on epiphytes. Therefore, *G. lacustris* higher consumption of autochthonous resources downstream during moderate turbidity and moderate/high light seasons may be attributed to *G. lacustris* preference for epiphytic diatoms and associated detritus. During high turbidity and low light conditions (autumn and winter), *G. lacustris* consume more amorphous detritus and leaf material than diatoms. During these seasons, *G. lacustris* had a more varied diet and also consumed macrophytes, fungi, and animal material at downstream sites (although in low proportions) and this may be because of the lower availability of autochthonous resources on cliff faces. Furthermore, *Gammarus* prefer conditioned (high microbial biomass) to unconditioned leaves (Bärlocher 1985) and, in this system, allochthonous inputs from tributaries may be a higher quality conditioned resource, due to higher water temperatures in tributaries. Similar to black flies, *G. lacustris* is an omnivorous and opportunistic feeder that is capable of shifting diets.

New Zealand mud snail diets also track changes in epilithon resource availability and NZMS consumed more autochthonous resources in the tailwaters than downstream during all seasons. New Zealand mud snails are classified as facultative scraper/grazers that feed on the periphyton/mucopolysaccharide matrix (an assemblage of diatoms, filamentous algae, algal exudates/mucilage, amorphous detritus, fungi, bacteria and other leaf, plant and animal material); therefore, they consume a variety of resources including diatoms, green algae, and plant and animal detritus (Haynes and Taylor 1984). New Zealand mud snail resource consumption was correlated with the epilithic resource

composition and NZMS were the only taxa correlated with all four of the dominant particles (diatoms, amorphous detritus, leaf material, and filamentous algae), confirming the importance of the periphyton matrix as a food resource. New Zealand mud snails thrive in autochthonously driven systems (Hall et al. 2006), and during summer when there is the highest availability of autochthonous resources, NZMS generally consumed more algae at all downstream sites than other seasons. In contrast, when the availability of autochthonous resources is lower during autumn, winter, and spring, NZMS generally consumed more amorphous detritus and leaf material at downstream sites. In addition, at downstream sites NZMS are most common in cobble bars with slow current velocities (personal observation). New Zealand mud snail preference for habitats with slower water velocities (Vinson 2004), which facilitate organic matter deposition, may explain the increase in consumption of allochthonous resources downstream during these seasons. Although NZMS consume allochthonous resources downstream, secondary production of NZMS is typically highest in autochthonously driven systems (Hall et al. 2006), and algae may be a better food resource. The low availability of autochthonous material downstream, particularly during high turbidity conditions, may explain their low abundance at downstream sites (Cross et al. unpublished data).

Chironomid diets tracked the availability of epilithic resources. Amongst taxa feeding on the epilithon, chironomids were the most highly correlated with epilithic resource composition of the dominant particles, diatoms and amorphous detritus, demonstrating the importance of epilithic resources for these taxa (Figure 5).

Chironomids generally consumed more allochthonous than autochthonous resources at

downstream sites during all seasons, except in the spring when similar proportions were consumed. The equal consumption of resources during the spring may be attributed to a number of factors. Although chironomids are most commonly classified as collector-gatherers, like other aquatic insects they are opportunistic and omnivorous and use multiple feeding modes (Berg 1995, Ferrington et al. 2008, Henriques-Oliveira et al. 2003); therefore, chironomids typically rely on a variety of resources. It has been previously demonstrated that factors such as larval size, sediment composition and food quality can influence chironomid feeding behavior (McLachlan et al. 1978, Hodkinson and Williams 1980, Berg 1995). Furthermore, unlike other taxa in this study, there are multiple species of chironomids present in this system, which may use different feeding modes, habitats, and food resources. Twenty-four species of chironomids have been reported in this system (Stevens et al. 1998) and four genera (*Cricotopus*, *Orthocladus*, *Eukiefferiella*, and *Tvetenia*: subfamily Orthocradiinae), were consistently collected for gut-content analysis in this study. These chironomids are typically found in a variety of habitats including rock and cliff faces, depositional zones, and associated with filamentous algae and other aquatic plants. Diet data of chironomids of all four genera, found in multiple habitats, were averaged at each site for each season, and therefore may mask spatial and seasonal diet trends that might exist for individual species. Further analysis of chironomid diets by size and genus may help elucidate diet shifts.

Shifts in food quality

Food resources in rivers vary in quality (i.e. algae is typically higher quality food than leaf material); therefore, changes in food resources consumed by macroinvertebrates

may influence their growth and production (Benke and Wallace 1980, Bird and Kaushik 1984, Rosi-Marshall and Meyer 2004). Autochthonous carbon (i.e. diatoms and filamentous algae) is more easily assimilated than allochthonous carbon (i.e. leaf material) (Benke and Wallace 1997), so in a system with seasonal or spatial changes in resource availability there may be shifts in macroinvertebrate production due to resource quality. The quality of allochthonous resources may also vary seasonally and longitudinally. In particular, higher temperatures in tributaries (seasonally relative to the mainstem) may increase microbial colonization of allochthonous resources, increasing the quality of the resource (by adding microbes as a food resource), or decreasing the quality as microbes consume it and the residual material becomes more recalcitrant (Short and Smith 1989, Abelho 2001, Graça and Canhoto 2006). Finally, a common food resource for macroinvertebrates in many large river systems, including the Colorado River, is amorphous detritus (Benke and Wallace 1997, Rosi-Marshall and Wallace 2002). The source (i.e. autochthonous versus allochthonous) of amorphous detritus may affect its quality and assimilation efficiency (Rosi-Marshall and Meyer 2004). In the tailwaters of Glen Canyon Dam, amorphous detritus may be primarily derived from autochthonous organic matter. In contrast, when primary production is low due to increased tributary-induced turbidity, amorphous detritus may be primarily derived from allochthonous organic matter from upland vegetation.

Because of varying assimilability, examining macroinvertebrate diets can cause misinterpretation of which food resources are actually supporting macroinvertebrate secondary production. Because autochthonous resources are assimilated more efficiently

than amorphous detritus and leaf material, they may contribute substantially to macroinvertebrate production, even in rivers where algal production and consumption is lower than allochthonous organic matter inputs and consumption (Thorp and Delong 2002). In the tailwaters of this system, autochthonous resources (predominantly diatoms) are consumed in higher proportions than allochthonous resources and contribute the greatest amount to macroinvertebrate production during all seasons. At downstream sites, amorphous detritus is generally consumed in higher proportions than diatoms; however, because of diatoms high assimilation efficiency, autochthonous resources still contribute substantially to macroinvertebrate production (Figure 5), particularly during moderate turbidity conditions (Table 7). Allochthonous resources (predominantly allochthonous amorphous detritus) also contribute substantially to downstream macroinvertebrate production (Table 7), particularly during high turbidity conditions when it dominates the diets of macroinvertebrates and supports a high percentage (31-93%) of their production, despite its low assimilability. I calculated the percent of allochthonously and autochthonously derived amorphous detritus (see methods), and the same assimilation efficiency, 0.1, was applied to both types of amorphous detritus for production attributable estimates. As discussed earlier, autochthonously derived amorphous detritus may be highly assimilable (Hart and Lovvorn 2003), and my calculation of production attributable to autochthonous resources may be underestimated. In contrast, during high turbidity conditions, when amorphous detritus is most likely from tributary flooding and allochthonously derived, the production attributable to allochthonous resources may be an underestimate. In conclusion, macroinvertebrate production in the tailwaters is

supported by autochthonous carbon, and downstream macroinvertebrate production is supported by a combination of autochthonous and allochthonous resources, during moderate turbidity conditions, and allochthonous resources during high turbidity conditions induced by monsoon tributary floods.

Serial discontinuity concept

Dams alter the natural state of rivers, influencing their physical and chemical properties, and ultimately changing the structure and function of downstream ecosystems (Baxter 1977, Power et al. 1996, Poff and Hart 2002). Restoration of river systems below dams can be assessed by examining the recovery of biophysical properties such as temperature, flow, and species distributions (Ward and Stanford 1983). The river continuum concept (RCC) predicts that longitudinal changes in physical characteristics of rivers from the headwaters to the mouth will be accompanied by a corresponding shift in energy inputs and the structure and function of biological communities (Vannote et al. 1980). The concept predicts that large rivers will be heterotrophic, with a macroinvertebrate community dominated by collectors because they are efficient processors of fine particulate organic matter (Vannote et al. 1980). The serial discontinuity concept (SDC) suggests that dams lead to discontinuities in the longitudinal characteristics predicted by the RCC, essentially resetting river conditions to that of a more upstream site. The SDC predicts that ecosystems will recover toward pre-dam conditions (or conditions predicted by the RCC) with increased distance from the dam and unregulated tributary inputs (Ward and Stanford 1983, 1995, Stanford and Ward 2001). System recovery has been evaluated by examining variables such as temperature,

flow regime, substratum composition, species abundance and diversity, and ratios of photosynthesis to respiration (Ward and Stanford 1983, Stanford and Ward 2001). The ability of a system to recover may be influenced by the size and operational mode of the dam, the longitudinal placement of the dam along the river continuum, the distance between dams, the size, number and discharge of unregulated tributary inputs, the extent of longitudinal, lateral and vertical connectivity between the river channel and floodplains, and biome type (Ward and Stanford 1995, Stanford and Ward 2001).

Some systems downstream of dams may never recover (Stanford and Ward 2001, Stevens et al. 1997). For example, in Grand Canyon, temperature, discharge and species diversity do not recover before the river encounters another reservoir (Stanford and Ward 2001, Stevens et al. 1997). Stevens et al. (1997) estimates that recovery of the thermal regime to pre-dam conditions would require 930 km of river. Hoover dam is only 400 km downstream of Glen Canyon Dam. The lack of recovery of the thermal regime in this system may strongly influence the recovery of macroinvertebrate biodiversity.

The Colorado River in Grand Canyon does not recover its thermal regime (i.e. there is little downstream warming (Wright et al. 2009)). However, my data demonstrate that macroinvertebrates consume tributary allochthonous carbon delivered to the mainstem, which may be similar to pre-dam conditions. The “recovery” of this pre-dam condition of reliance on tributary carbon is a novel metric for ecosystem recovery downstream of a dam not previously considered in the SDC. This finding suggests that there may be the potential for recovery of the food web dynamics (and possible

concomitant increases in diversity), if other aspects of the river were restored (i.e. thermal or flow regime).

Conclusion

The aim of this study was to examine how macroinvertebrates diets vary spatially and temporally in the Colorado River downstream of Glen Canyon Dam. My data demonstrate that tributary-derived allochthonous carbon and locally produced autochthonous carbon are important food resources for downstream macroinvertebrates. The macroinvertebrates in this system are generally opportunistic, facultative feeders, and their diets reflect changes in organic matter availability. *S. arcticum* is the most common macroinvertebrate taxon in sites downstream of the tailwaters, perhaps due to their ability to consume allochthonous tributary carbon. Macroinvertebrate groups such as filter-feeders may recover to pre-dam conditions if thermal and flow regimes were restored, even if organic matter inputs from upstream were not restored, because they may be able to effectively utilize tributary allochthonous inputs as a food resource.

Currently, more than 42,000 large dams obstruct rivers throughout the world (ICOLD 1998). The United States contains over 5,000 large dams and ranks second only to China in terms of the number of large dams (Benke 1990, ICOLD 1998). While these dams provide a source of water and energy, they also alter the physical habitat, temperature and flow regime of rivers and contribute significantly to the degradation of our freshwater ecosystems (Baxter 1977, Ward and Stanford 1979, Petts 1984, Nilsson and Berggren 2000). The decrease in the biotic integrity of rivers associated with large dams has led to the extinction and endangerment of over two-fifths of freshwater fishes in

the U.S. (McCully 1996). Given that removal of large dams is not usually an option (Whitelaw and MacMullan 2002, Hart et al. 2002), effective management of dams is essential to protect biotic integrity. Understanding which resources support food webs may help to better manage dam operations to increase macroinvertebrate production and even diversity and may ultimately aid in fish conservation. This research provides evidence that macroinvertebrates in dammed systems are capable of shifting diets to access changing resources. However, although the availability of food resources in dammed systems may recover toward pre-dam conditions due to tributaries, the macroinvertebrate diversity and production may not recover without the restoration of physical characteristics (i.e. water temperature and flow regime).

CHAPTER TWO

EXPLORING A POTENTIAL PRODUCTIVITY SUBSIDY USING A NOVEL TRACER IN THE COLORADO RIVER BELOW GLEN CANYON DAM

Abstract

In this study I examined algal taxonomic content of epilithon, epicremnon, seston, and macroinvertebrate diet at six sites in the Colorado River downstream of Glen Canyon Dam to address whether primary production in the tailwaters may serve as a resource subsidy to macroinvertebrates downstream. To address this I attempted to identify algal species to use as novel tracers, to examine if algal cells produced in tailwaters were used as a resource by macroinvertebrates downstream. In addition, one indicator species (*Fragilaria crotonensis* Kitton) was used to assess algal transport and survival, helping to further address the potential for tailwater production to support downstream macroinvertebrates. Tailwater algal assemblages consistently differed from downstream assemblages, allowing a list of species that could serve as potential indicators for the tailwater and downstream sites to be identified. Although many of the species were not common in the system, their specificity to tailwater or downstream sites made them useful indicators, and helped to identify the origin of macroinvertebrate food resources. I concluded that macroinvertebrates residing in reaches of the Colorado River well downstream of Glen Canyon Dam consume a combination of tailwater and downstream

(site-specific or tributary species) algae, but tailwater primary production does not solely fuel downstream macroinvertebrates, and may not serve as an important resource subsidy. Algal indicators were useful subsidy tracers in this system, and this method may be useful for addressing food web subsidy questions in other systems.

Introduction

In aquatic ecosystems the importance of resource subsidies from adjacent habitats and ecosystems has been well documented (Ward 1989, Bilby et al. 1996, Polis et al. 1997, Nakano et al. 1999). A basic tenet in stream ecology is that upstream and downstream ecosystems are linked via the transport of nutrients and organic matter (Vannote et al. 1980); therefore, upstream habitats can provide resource subsidies to downstream food webs. Although the transport of resources from upstream reaches to downstream ecosystems has been well documented (Fisher and Likens 1973, Angradi 1991, Cushing et al. 1993, Webster et al. 1999, Wipfli et al. 2007), the extent to which these resources are exploited or subsidize downstream food webs is less understood and still requires further research (Wipfli et al. 2007).

Recently, food web studies in stream ecosystems have focused on examining the potential importance of the exchange of resources between the stream and riparian zone (Nakano and Murakami 2001, Power 2001, Baxter et al. 2005). In large rivers, particularly in dammed systems, downstream food webs can also be subsidized by resources from lakes and reservoirs (Petts 1984, Doi et al. 2008, Mercado-Silva et al. 2008); however, the importance of the subsidy may decline as distance from the reservoir increases (Ward 1975, Doi et al. 2008, Mercado-Silva et al. 2008). Similar to reservoir

subsidies, the productive tailwaters downstream of dams may also provide a resource subsidy to downstream ecosystems. For example, in the Colorado River, the completion of Glen Canyon Dam in 1963 substantially reduced sediment loads in the river, increasing light levels and algal production in the tailwaters below the dam (Stevens et al. 1997). Food web analyses in this system have focused on the importance of tailwater-produced autochthonous resources for macroinvertebrates (Pinney 1991, Shannon et al. 1994) and it has been suggested that the highly productive tailwater below Glen Canyon Dam may be a resource subsidy to downstream food webs (Blinn et al. 1994, Walters et al. 2000). However, downstream food webs may also be fueled by local primary production and inputs of organic matter from tributaries. Tributary flooding contributes approximately 500,000 metric tons of particulate organic matter to the mainstem of the Colorado River annually (ca. 50 times the amount of algal production) (Kennedy et al. unpublished data) and evidence indicates that this organic matter is exploited by macroinvertebrates and fish downstream of tributary confluences (Angradi 1994, Blinn et al. 1998, Wellard Kelly (Chapter 1), Zahn et al. unpublished data). Furthermore, epiphytic diatoms on *Cladophora glomerata* (L.) Kütz., the dominant filamentous alga in the tailwaters, have been shown to be heavily exploited by macroinvertebrates in the tailwaters (Pinney 1991, Stevens et al. 1997). Downstream of the tailwaters, *C. glomerata* densities decline significantly (Carothers and Brown 1991). The extent to which autochthonous production in the tailwaters of Glen Canyon Dam subsidizes food webs downstream is not currently known. Data presented in Chapter 1 suggest that, during

monsoons especially, downstream macroinvertebrates consume allochthonous resources.

However, during seasons with lower turbidity, it is not clear if the algae present in macroinvertebrate diets is a resource subsidy from the tailwater or if these autochthonous resources are produced *in situ* at downstream sites.

To resolve this issue, I used algal taxa with distributions limited to specific river reaches as tracers, to examine if food resources from one area were exploited by primary consumers in another. Tracers have proven useful for addressing a number of important ecological questions. For example, otolith microchemistry has been used to track migration patterns and habitat use of fishes (Ingram and Weber 1999, Secor et al. 1995, Clarke et al. 2007). Trace elements can help to identify the source, distribution and accumulation of pollutants in a variety of ecosystems (Rizzutto et al. 2006, Barber et al. 2006). Detection and dispersion of larvae of invasive invertebrate larvae in aquatic systems has been accomplished using molecular-genetic markers (Harvey et al. 2009), Transport length and uptake of particles in streams has been documented using radio-labeled and fluorescently labeled particles (Cushing et al. 1993, Hall et al. 1996, Thomas et al. 2001, Newbold et al. 2005), and stable isotopes allow resource use and energy flow through food webs to be tracked (Hamilton et al. 1992, Peterson 1999). Stable-carbon isotopes ($^{13}\text{C}/^{12}\text{C}$) are the typical tracers used in food web studies to distinguish which basal resources are utilized by consumers (Rounick et al. 1982, Hamilton et al. 1992, Rosenfeld and Roff 1992, Bastow et al. 2002), because terrestrial and aquatic plants often differ in their $\delta^{13}\text{C}$ signature (Rounick and Winterbourn 1986). In addition, natural variation in algal $\delta^{13}\text{C}$, attributed to differences in current velocity or algal productivity

(Peterson et al. 1993, Finlay et al. 1999), can also help to spatially differentiate between utilization of algae produced in different habitats (Finlay et al. 1999).

Although, stable isotopes can be useful for elucidating spatial patterns in algal resource use in some systems (Finlay et al. 1999), algal $\delta^{13}\text{C}$ may be less useful in systems where $\delta^{13}\text{C}$ signatures do not significantly differ among sites (France 1996) or if there is great variability in algal $\delta^{13}\text{C}$ signatures (France 1995a). In particular, identification of the basal resources used by consumers can be difficult when there is not sufficient separation or characterization of dietary end-members (Hamilton and Lewis 1992). For example, many aquatic consumers feed on fine particulate organic matter (FPOM), a mixture of live algae, and detritus derived from algae, consumer feces, or terrestrial and aquatic plants (Hamilton and Lewis 1992). Therefore, without isotopic separation of algal and detrital material it may be difficult to determine the importance of the different basal resources (Hamilton and Lewis 1992). These difficulties demonstrate that other tracers may be useful to address more specific questions in trophic subsidy studies.

A novel tracer may be particularly useful to examine if primary production in the tailwaters is being exploited downstream, because the tailwater and downstream ecosystems may support algal communities that differ in taxonomic content (Czarnecki and Blinn, 1978). In particular, community assemblages in the tailwaters may differ from downstream communities due to physical and chemical changes induced by tributary inputs. The serial discontinuity concept (SDC) predicts that tributaries downstream of dams may ameliorate some of the physicochemical condition changes induced by dams

(Ward and Stanford 1983, Stevens et al. 1997), inducing differences between tailwater and downstream communities (Takao et al. 2008). Tributary inputs to the Colorado River contribute high amounts of suspended sediment and organic matter, resulting in reduced light levels and concomitant reductions in algal production (Yard 2003, Hall et al. unpublished data). Furthermore, water temperature in the Colorado River increases with distance from Glen Canyon Dam (2-10 °C) (Wright et al. 2009), a change that has been shown to influence the species composition, growth, production and distribution of aquatic communities (Vannote and Sweeney 1980, Blinn et al. 1989, Vinson and Hawkins 1998, Arscott et al. 2001, Dallas 2008).

Changes in the physical and chemical characteristics of the Colorado River induced by tributary inputs may lead to changes in the algal community assemblage in the river (Czarnecki and Blinn, 1978). Algal communities, specifically diatoms, are important indicators of change in aquatic ecosystems (Dixit et al. 1992, McCormick and Cairns 1994, Pan et al. 1996), and are useful for water-quality biomonitoring (Reavie and Smol 1998, Rott et al. 1998, Stevenson and Pan 1999). The structure of benthic algal communities can be affected by suspended sediment levels, light conditions, temperature, water chemistry, herbivory, flow conditions and disturbance (Peterson 1987, Blinn et al. 1989, McCormick and Stevenson 1989, Hardwick et al. 1992, Pan and Lowe 1994, Pan et al. 1996). Because algal communities reflect environmental conditions and respond quickly to physical, chemical and biological changes, both communities and individual species may be used as taxonomic indicators of environmental and habitat conditions in rivers (Dixit et al. 1992, McCormick and Cairns 1994). Rare taxa or specialists (species

that have narrow optima and tolerances to certain environmental variables (Dixit et al. 1992, Enache and Prairie 2002, Pither and Aarssen 2005)) may be useful indicators because they may reflect specific environmental habitat or site conditions.

In the Colorado River, if longitudinal variation in algal species composition occurs, it may allow for certain species to be used as tracers. Algae are an important food resource for macroinvertebrates throughout the system (Wellard Kelly (Chapter 1) and algal tracers may elucidate whether macroinvertebrates along the length of the river rely on algal production generated locally or on algae produced in the tailwaters of Glen Canyon Dam and transported downstream (Figures 7 & 8). Similarly, if algal assemblages in tributaries differ in taxonomic structure from those in the mainstem (Czarnecki et al. 1976), tributary species representation in macroinvertebrate diets would also demonstrate the role of tributary inputs of autochthonous production to macroinvertebrates in the Colorado River food web.

The objective of this study was to determine if species-level identification of algae can be used to elucidate whether macroinvertebrates rely on upstream food resources versus site-specific/downstream food resources. Examination and comparison of the algal communities comprising the epilithon (rock/cobble), epicremnon (cliff/talus), seston, and macroinvertebrate diets, at six sites over the 226 mile stretch of the river was used to assess the extent to which tailwaters provide a trophic subsidy to macroinvertebrate communities downriver.

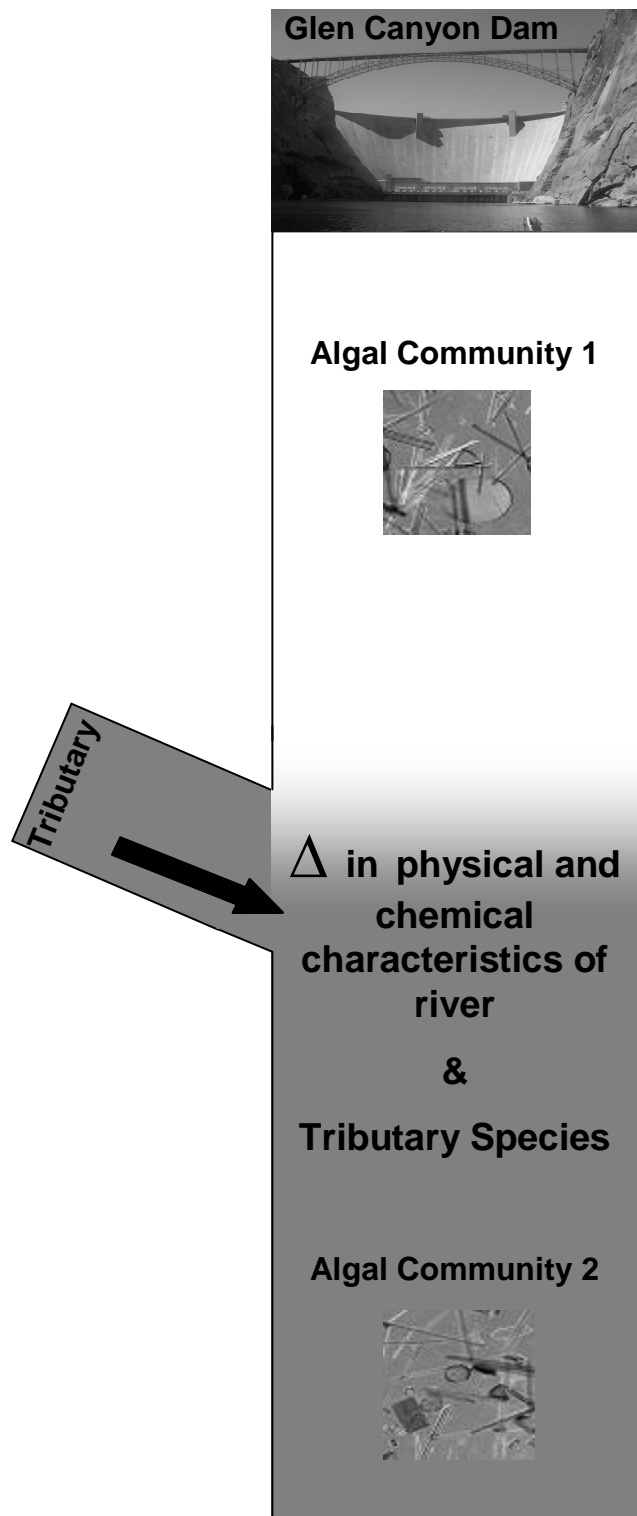


Figure 7. Effects of the dam and tributary inputs on algal communities.

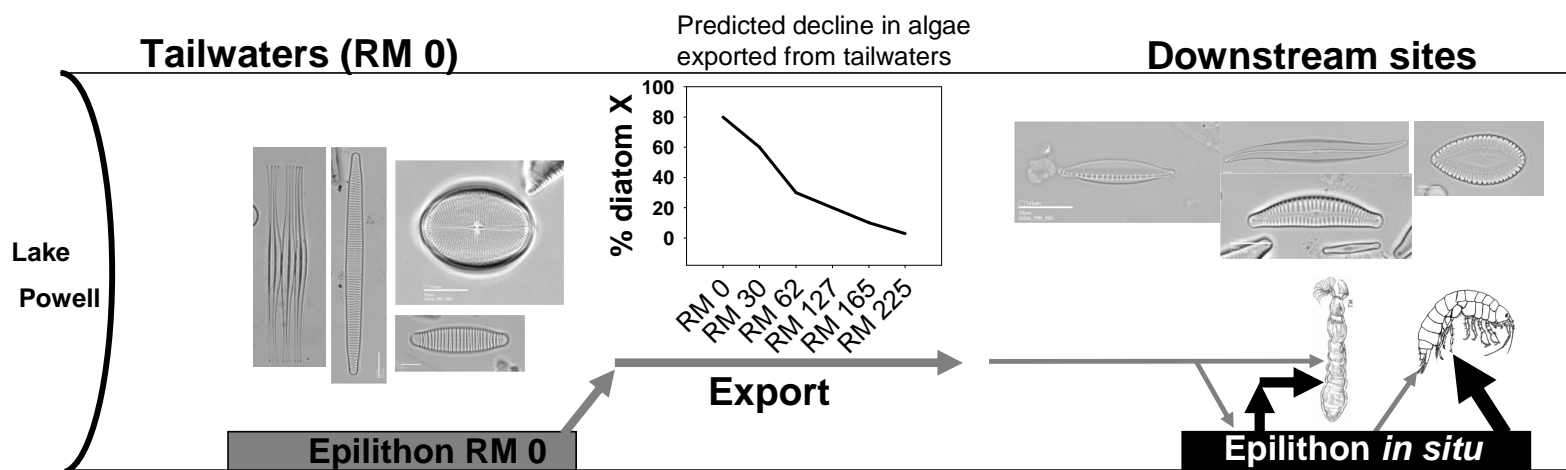


Figure 8. Potential algal sources for macroinvertebrates at downstream sites.

The research question addressed in this study was: Can species-level identification of algae elucidate highly site-specific feeding versus reliance on tailwater food resources, and more specifically: 1) Does algae from the tailwaters move/survive downstream?; 2) Are there species which may be useful indicators for the tailwaters versus downstream sites?; 3) Do macroinvertebrates downstream of the tailwaters consume indicator species that originate from the tailwaters?; 4) Do macroinvertebrates downstream of the tailwaters consume indicator species that originate from downstream sites?

I predict the identity of algal species consumed by macroinvertebrates will shift in conjunction with longitudinal changes in the taxonomic content of algal assemblages in the river (Hardwick et al. 1992). In addition, I predict that algal species will be useful indicators and will help to examine the importance of upstream and site-specific resources for macroinvertebrates. I also predict that tailwater algae will be able to move/survive downstream, although in low numbers, and that downstream macroinvertebrates will eat mostly downstream diatoms with limited amounts of tailwater diatoms.

Methods

Study sites and sampling protocol

This study was conducted in the Colorado River (CR) in Grand Canyon, Arizona (36° 03'N, 112° 09' W). Six sites were sampled over a 226 mile (363 km) reach downstream of Glen Canyon Dam (GCD) (Figure 2). Sites were selected based on general canyon characteristics, the location of major tributary inputs, prevalence of

humpback chub populations (RM 62 and 127), and based on their long-term use as sediment and geomorphology monitoring sites (RM 30, 62 and 127). The first site, Lee's Ferry (RM 0) is located in Glen Canyon and encompasses a 15.7 mile (25 km) reach extending from the downstream end of the Glen Canyon Dam to Lee's Ferry. This tailwater reach is above the confluence of the Paria River, and is consistently low in turbidity. The five downstream sites are located in the Grand Canyon, from Marble Canyon to Diamond Creek. The second site, RM 30, is located in the Marble Canyon section (Redwall gorge reach) of the Grand Canyon, approximately 29 miles downstream of the Paria River, the first major tributary below the dam. The third site, RM 62, is located in the beginning of the Central Grand Canyon section (Furnace flats reach) below the Little Colorado River (LCR), the largest tributary. The fourth site, RM 127, is also located in the Central Grand Canyon section (Middle granite gorge reach) below a number of smaller tributaries including Bright Angel, Shinumo and Fossil Creeks. The fifth site, RM 165, is located in the Western Grand Canyon section (Lower canyon reach) below Tapeats, Kanab and Havasu Creeks. The final site, RM 225, is also located in the Western Grand Canyon section (Lower granite gorge) and extends to Diamond Creek (a small tributary). Sites, RM 30 and 62, are located in wider sections of the canyon and sites, RM 127 and 165, are within the narrowest canyon sections (Stevens et al. 1997).

Algal assemblage analysis

The taxonomic structure of algal assemblages were quantified from seston, epilithic (rock/cobble faces), and epicremnic (cliff faces) samples at each of the six collection sites during January 2007. These results were compared to algae within the

guts of *Simulium arcticum* and *Gammarus lacustris* collected from the same sites, during January 2007, to assess whether macroinvertebrates rely on upstream resources (produced in the tailwater reach below Glen Canyon) or site specific downstream resources. In addition, separating out algal communities from seston, epilithic and epicremnic habitats allowed for assessment of specific locations of macroinvertebrate feeding activity.

Resource and macroinvertebrate collection

Suspended fine particulate organic matter (seston) composition samples (two to three per site and date) were collected from the thalweg at each site by sieving river water through a 250- μm sieve and filtering ca. 40-300 ml onto 0.45- μm grided Metrical® membrane filters (Pall Corp., Ann Arbor, MI). Epilithic biofilms were scraped from two to three rocks collected from the river bed and from two to three cliff faces, using a scraping sucking device. A 30-40 ml subsample of biofilm slurry from individual rocks and cliffs was preserved in the field with Lugol's solution (Prescott 1978).

Macroinvertebrates were haphazardly collected throughout the reaches of the six sites, preserved in Kahle's solution (Stehr 1987) in the field, and returned to the lab for gut-content analysis.

Resource composition slide preparation

To examine the taxonomic structure of algal assemblages available for macroinvertebrate consumption, I quantified the relative abundances of algal species collected from the seston and epilithic and epicremnic biofilms. For epilithic and epicremnic biofilms, I filtered 0.1-5.0 ml subsamples from preserved field collections

onto 0.45 μm gridded Metrical® membrane filters (Pall Corp., Ann Arbor, MI). Seston, epilithic and epicremnic filters were mounted on slides for preservation using Type B immersion oil for subsequent enumeration. Two to three slides were analyzed as replicates for each habitat at each site.

Macroinvertebrate slide preparation

Gut-content analysis (Rosi-Marshall and Wallace 2002) was used to examine the taxonomic structure of algal assemblages in the diets of *Simulium arcticum* (Insecta: Diptera: Simuliidae) and *Gammarus lacustris* (Crustacea: Amphipoda: Gammaridae). *Simulium arcticum* was selected for algal assemblage analysis because they are filter-feeders and their diets may reflect algae that are transported in the water column. *G. lacustris* was selected because they are shredders that feed on the benthos and prefer epiphytic diatoms in this system (Pinney 1991); therefore, their diets may indicate the transport and deposition of algae from upstream sites. Dissected gut contents were drawn onto (25mm, 0.45 μm) gridded Metrical® membrane filters (Pall Corp., Ann Arbor, MI) and mounted on slides for preservation using Type B immersion oil. I used guts from one to four individual macroinvertebrates for each slide. Two to three slides were analyzed for each taxon at each site.

Microscopy

Algal species were identified at 1000x magnification using an Olympus BX50 or BH2 microscope equipped with a camera for image analysis. The following taxonomic references were used for identifications: Czarnecki and Blinn (1977), Czarnecki and Blinn (1978), Patrick and Reimer (1966), Patrick and Reimer (1975). At least 300 valves

were identified from each slide or ten full transects were scanned, whichever occurred first. During identification each valve was recorded as live or dead by examining intact chloroplasts. All calculations included both live and dead cells unless otherwise noted. One to three slides were analyzed for each habitat (seston, epilithon and epicremnon) at each site, and gut contents were quantified from two to three slides for each macroinvertebrate taxon at each site. The relative abundance of individual algal species was calculated for each sample and used to calculate the mean relative abundance of each algal species at each site, for each habitat and macroinvertebrate taxa.

Algal movement and survival

To address whether algae from the tailwaters are transported and survive downstream, *Fragilaria crotonensis* Kitton, a dominant planktonic diatom in Lake Powell and its tailwaters, was selected from seston samples to serve as a tracer for autochthonous tailwater production. The total number of live versus dead *F. crotonensis* cells per milliliter of filtered seston was compared across all sites, to assess the potential for tailwater algae to move and survive downstream and be consumed by macroinvertebrates. The relative contribution of *F. crotonensis* to the total number of cells in a seston sample was calculated to compare to the proportions measured in macroinvertebrate diets.

Algal transport distance and deposition velocity

To estimate longitudinal displacement of algal cells downstream and determine how quickly it may be deposited on the benthos or destroyed, I used methods described in Thomas et al. (2001). I calculated the expected transport distance (S_p) of the tailwater-

indicator species, *F. crotonensis*, using the formula, $S_p = 1 / K_p$, where K_p represents the longitudinal loss rate of a particle and is the slope of the linear regression of the natural logarithm of the average number of *F. crotonensis* cells with distance downstream from RM 0 to RM 62. I only used the first three sites (RM 0, RM 30, and RM 62) for the linear regression, to minimize the sampling of different pulses (days) of water (i.e. water released from the dam on Monday, was collected at RM 30, but water released from the dam on Tuesday was collected at RM 62). Deposition velocity (V_{dep}) was also calculated for *F. crotonensis*, to examine how quickly it may be deposited on the benthos or destroyed. V_{dep} was calculated using the formula, $V_{dep} = V_{wat}d / S_p$, where V_{wat} and d are mean water velocity and depth, respectively (Thomas et al. 2001). The mean water velocity during January 2007 was calculated for the RM 0, 30 and 62 reaches, and the average velocity of the reaches, 0.9 ms^{-1} , was used for the depositional velocity calculation. The mean depth, 6.8 meters, used in this calculation, was calculated as the average depth of the RM 0, 30 and 62 reaches.

Algal species as indicators of tailwater production

Seston, epilithon, epicremnon and macroinvertebrate algal community comparisons

A variety of techniques were used to assess whether species-level identification of algae can elucidate highly site-specific feeding versus reliance on upstream resources. I examined the algal community to find algal indicators of: 1) specific sites (only found at that site), 2) specific habitats, 3) tailwater exclusively, and 4) downstream exclusively.

Multivariate analyses

The taxonomic structure of algal assemblages at six sites for each habitat (seston, epilithon, epicremnon) was compared using detrended correspondence analysis (DCA, Hill and Gauch 1980) with the program DECORANA (Hill 1979). DCA analyses were conducted comparing assemblages at all six sites in the seston, epilithon and epicremnon. Mean DCA axis scores generated from replicate site samples for each habitat were plotted in ordination space based on the relative abundance of common taxa. Algal species were included in the analysis if they comprised an average of \geq three percent of the assemblage or \geq three percent of the assemblage in one replicate, but were also present in all three replicates. Ordination biplots of species scores were plotted concurrently to examine which species contributed to assemblage differences. Species that contributed to differences among sites were considered potential indicator species for tailwater and downstream sites. The presence/absence of these species in macroinvertebrate diets may indicate where macroinvertebrates are acquiring their resources.

Area plots/dominant taxa

Area plots of relative abundances of common taxa in the assemblages (the same taxa used for DCA) at the six sites were used to examine community patterns and to compare the longitudinal trends for individual algal species and assemblages, among habitats. Area plots revealed which common taxa may be useful tailwater and downstream site indicators, based on their changing abundance throughout the system.

Rare taxa as indicators

I developed a standard process to identify rare taxa that may be useful indicators of tailwater production (Figure 9). All species that were found exclusively in tailwater samples were classified as tailwater indicators. Species found exclusively in one of the three habitats, or was dominant in that habitat relative to other habitats, were further classified as tailwater indicators of seston, epilithon, or epicremnon. Four lists were generated from this analysis: 1) Tailwater indicator species, 2) Seston tailwater indicator species, 3) Epilithic tailwater indicator species, and 4) Epicremnic tailwater indicator species. Taxa were also selected as tailwater indicators, if present in the seston at upstream and downstream sites, but only present in the epilithon or epicremnon upstream.

The same process was used to identify downstream (non-tailwater) indicator species (Figure 9). First, all species that were found exclusively in downstream samples were classified as downstream indicators. Next, species were classified as specific habitat indicators (seston or hard substrate). Hard substrate indicators were further classified as epilithic or epicremnic downstream indicators. Finally, all species identified as downstream indicators were compared to macroinvertebrate diet algal assemblages. If a species identified as a downstream indicator was present in the diet of a macroinvertebrate from the tailwaters, it was discarded. Also if a species was never identified in the diet of a macroinvertebrate it was also discarded, as they were not useful for determining if macroinvertebrates acquire their resources from the tailwaters or downstream sites.

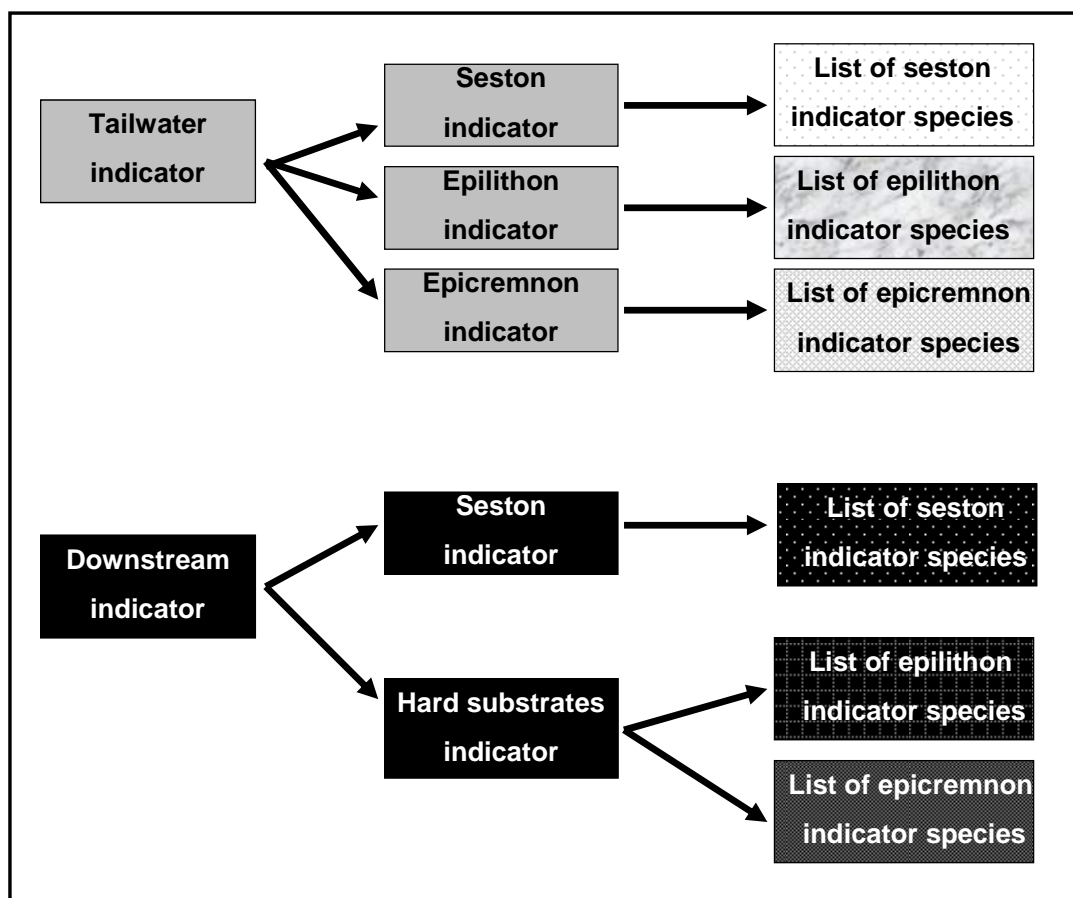


Figure 9. Flow chart used to classify tailwater and downstream indicator species.

Relative contribution of tailwater indicator species to macroinvertebrate production

Surface areas for each algal species were estimated from length and width measurements of greater than ten cells for common species and from one to five cells for rare species (note: geometric formulae approximating cell shapes were only applied for circular and elliptical shaped cells, all other cell surface areas were estimated as the product of the length and width). The relative surface area of each algal species was calculated for each macroinvertebrate diet.

The proportion each tailwater indicator species comprised of the total surface area in each macroinvertebrate's diet algal assemblage was used to calculate the percent area each tailwater indicator species comprised relative to the area of other particle types (ie amorphous detritus, leaf material, other diatoms) consumed by each taxa (see Chapter 1). Food-specific assimilation efficiencies (percentage of a food type that a macroinvertebrate is able to assimilate) and net production efficiencies (an estimate of the ratio of tissue production to energy assimilation) were used to estimate the relative contribution of food types and tailwater indicator diatoms to production (see Chapter 1). The relative contribution of each tailwater indicator diatom to macroinvertebrate production was calculated for both the tailwaters and downstream sites, to estimate the amount that tailwater diatoms may subsidize downstream macroinvertebrates.

Results

In this study, 159 algal species were identified from the sestonic, epilithic, and epicremnic algal assemblages, and in the diets of *S. arcticum* and *G. lacustris*. Of these, 155 species were diatoms and four species were filamentous green algae. Despite the relatively high species richness, fewer than 26 species comprised over 70 percent of most communities (Figures 10, 11, and 12). Ultimately, five taxa were identified as tailwater indicators and of these five, only two were present solely in the tailwaters. One seston tailwater indicator, *F. crotonensis*, was chosen to assess the transport and survival of algae downstream, because of its planktonic nature and dominance in the tailwater seston community. Nine taxa were identified as downstream indicators, seven of which were identified to species level.

Longitudinal transport and survival of Fragilaria crotonensis

Both live and dead cells of *F. crotonensis* were encountered in downstream sites, but in much lower numbers than in tailwaters (Figure 13). Dead *F. crotonensis* cells comprise 92 percent of total *F. crotonensis* cells in the tailwaters. The densities of dead *F. crotonensis* cells decrease at downstream sites (Figure 13). Live cells comprise only eight percent of total *F. crotonensis* cells in the tailwaters and the density of live *F. crotonensis* cells increased at some downstream sites (Figure 13). In addition to the decline of *F. crotonensis* in the seston, it also declines as a proportion of the *S. arcticum* diet algal assemblage (Figure 14). In the tailwaters, 26 percent of all particles in *S. arcticum* diets are *F. crotonensis* (Figure 14). At downstream sites, it is less than four percent of all particles consumed by *S. arcticum* (Figure 14).

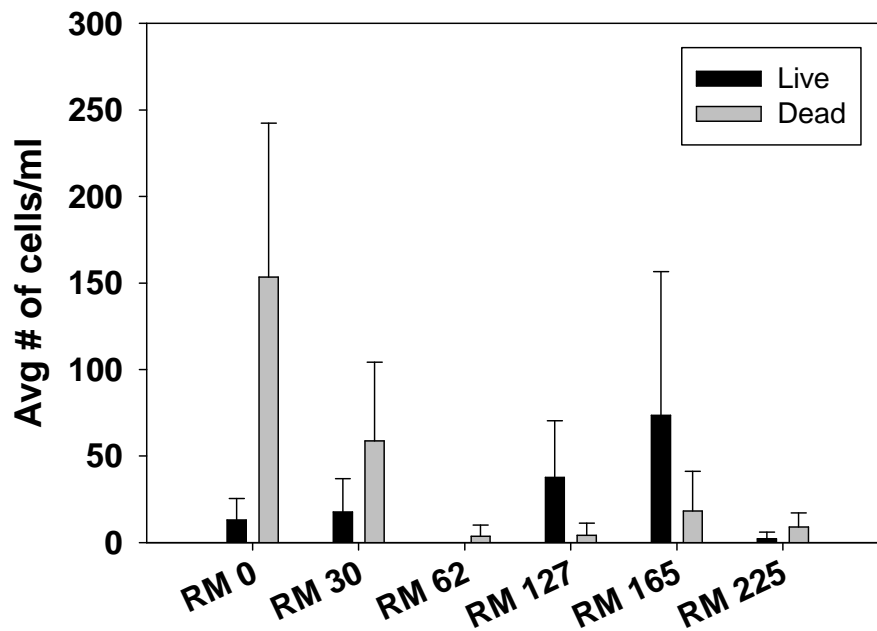


Figure 13. Mean number and standard deviation (SD) of live and dead *F. crotonensis* Kitton cells per milliliter of filtered suspended organic matter (seston) at six sites downstream of the dam. Seston samples collected at each site were sampling different pulses of water released from the dam (i.e. we did not follow and sample the same water at each site in the Canyon).

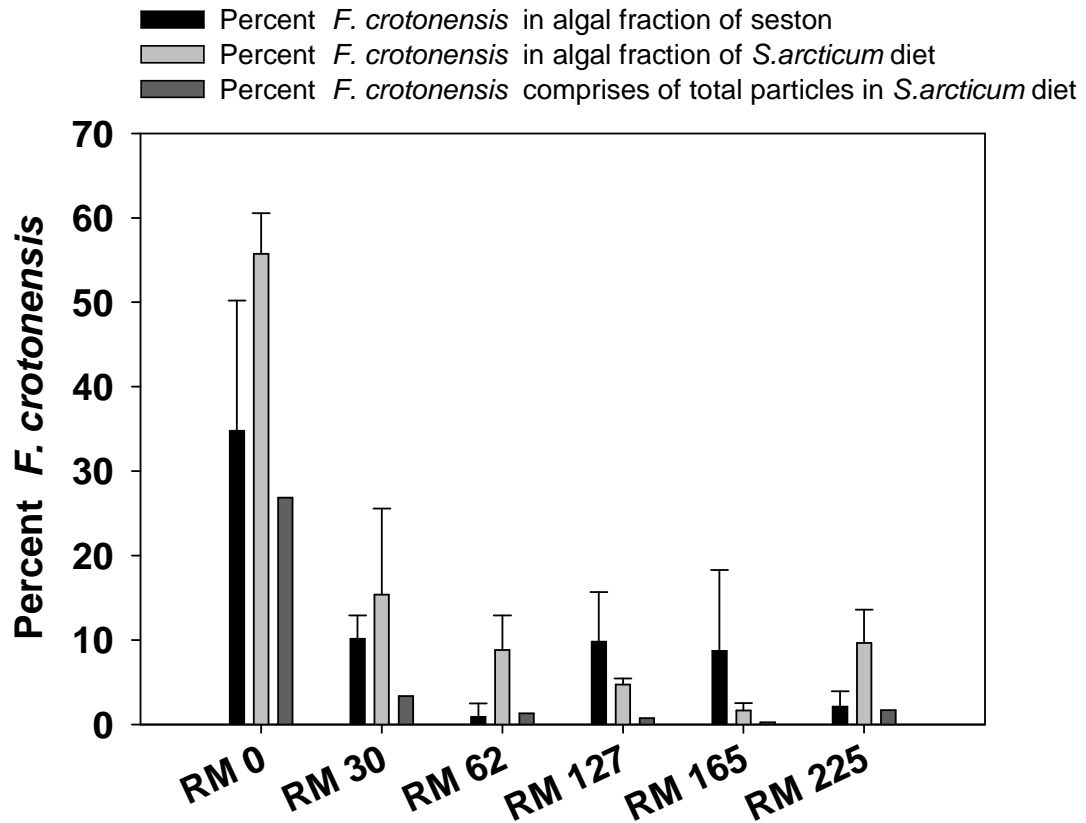


Figure 14. Mean percent and standard deviation (SD) of *F. crotonensis* Kitton in the seston algal assemblage, and *S. arcticum* diet algal assemblage, at six sites downstream of the dam. And the mean percent *F. crotonensis* comprises of total particles in *S. arcticum* diets at six sites downstream of the dam.

Algal transport distance and deposition velocity

I estimated that cells of *F. crotonensis*, originating from the tailwater or outflow of Lake Powell into the Colorado River travel, on average, approximately 15.5 miles downstream before deposition on the benthos, or destruction via loss by mechanical disruption or ingestion by macroinvertebrates, occurs. The depositional velocity for an *F. crotonensis* cell was calculated to be 0.24 mm s^{-1} .

Dominant taxa as indicators

Determination of seston indicator species

DCA analysis of seston algal assemblages at the six sites revealed differences between algal assemblages in tailwaters and downstream assemblages (Figure 15). Downstream sites fell into similar ordination space, negating the ability to identify useful downstream indicator taxa for individual downstream study reaches. The tailwater assemblage separated from the downstream assemblages based on differences in the relative abundances of the following taxa: *F. crotonensis*, *Diatoma vulgare* Bory, *Ellerbeckia arenaria* (Moore) R.M. Crawford, *Cymbella lunata* W. Smith, *Nitzschia dissipata* (Kützinger) Grunow, *Fragilaria* sp. 4, and green algae zoospores (Figure 15). Of these, *Fragilaria crotonensis* contributed most strongly to the tailwater. Based on the DCA results, *F. crotonensis*, *D. vulgare*, and *E. arenaria* were classified as tailwater seston indicators. When downstream sites were considered collectively, three additional taxa were classified as downstream seston indicators: *C. lunata*, *N. dissipata*, and *Fragilaria* sp. 4.

Examination of relative-abundance data of common sestonic taxa (Figure 10) allowed refinement of species indicator lists. As a result of this analysis identity of seston tailwater indicators remained unchanged, but, finer, more reach-specific (location shown parenthetically) identification of downstream indicator taxa was possible. These included: *Fragilaria* sp. 4 (RM 62); *Amphora perpusilla* (Grunow) Grunow (RM 125); *C. lunata* and *N. dissipata* (RM 225).

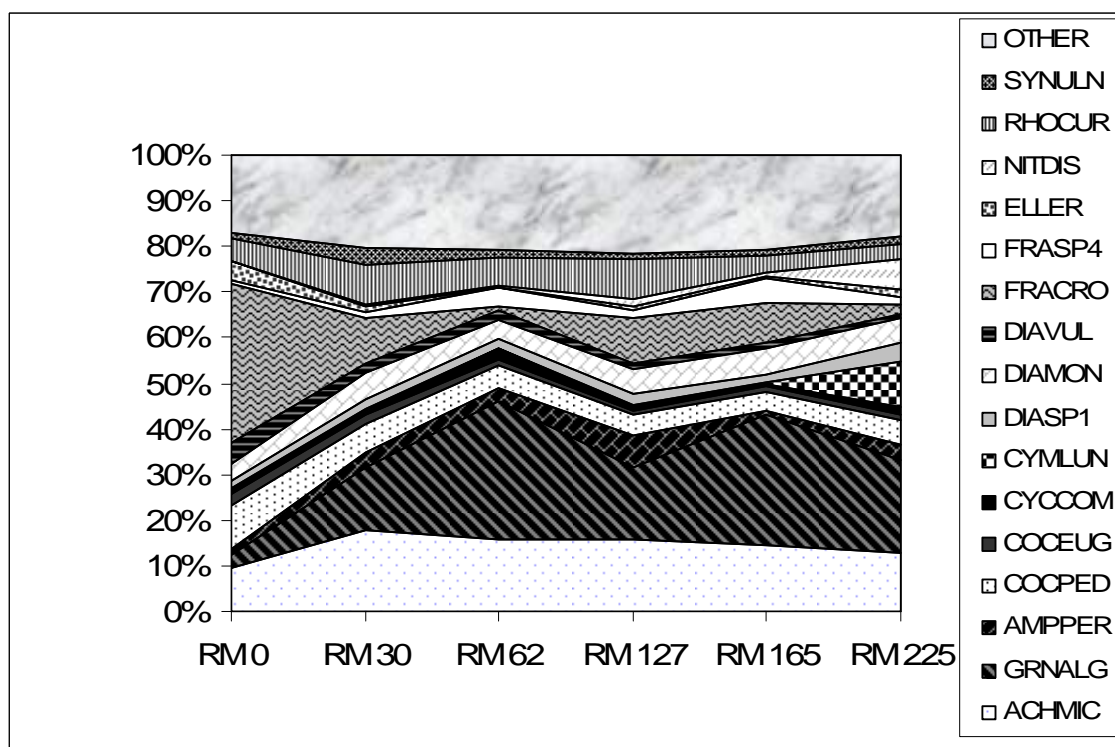


Figure 10. Area plot of dominant taxa (mean is $\geq 3\%$ of the assemblage) in seston at six sites downstream of the dam (see appendix B: Appendix 2.2 for abbreviations).

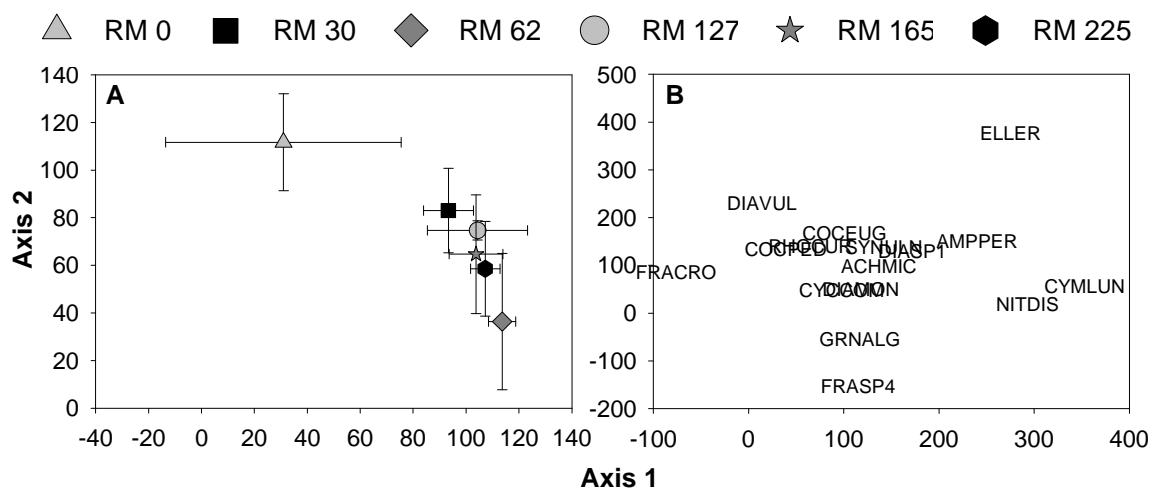


Figure 15. A) DCA ordination of mean (SD) sample scores for seston in January 2007 at six sites downstream of dam. Eigenvalues for axis 1 = 0.362; for axis 2 = 0.0078. B) Corresponding species scores (see Appendix B: Appendix 15 for abbreviations).

Determination of epilithon indicators

DCA analysis of epilithic algal assemblages at the six sites clearly separated algal assemblages in the tailwaters from those downstream, with the greatest separations between the tailwaters and RM 30 and 62 (the sites below the two largest tributaries) (Figure 16). Differences were driven by the following taxa: *Fragilaria* sp. 4, *Nitzschia denticula* Grunow/*Denticula elegans* Kützing, *Synedra ulna* (Nitzsch) Ehrenberg, *D. vulgare*, *A. perpusilla*, *Reimeria sinuata* (Gregory) Kociolek & Stoermer, *Encyonema prostratum* (Berkeley) Kützing, *E. arenaria*, *Nitzschia fonticola* (Grunow) Grunow, and *Gyrosigma spencerii* et varieties. *Fragilaria* sp. 4, *N. denticula*/*D. elegans* Kützing, *S. ulna*, and *D. vulgare* were classified as tailwater indicators; and *A. perpusilla*, *R. sinuata*, *E. prostratum*, *E. arenaria*, *N. fonticola*, and *G. spencerii* et varieties, were classified as downstream indicators.

Examination of relative-abundance data of common epilithic taxa (Figure 11) allowed refinement of species indicator lists and more reach-specific (location shown parenthetically) downstream indicator taxa were identified. Four additional downstream indicator taxa were also identified. These included: *A. perpusilla*, *E. prostratum* (RM 30 and 62); *N. dissipata*, *N. fonticola*, and *G. spencerii* et varieties (RM 127 and 165); *R. sinuata*, *Navicula cryptotenella* Lange-Bertalot, *Cymbella affinis* Kützing, and *Navicula tripunctata* (O.F. Müller) Bory (general downstream indicators).

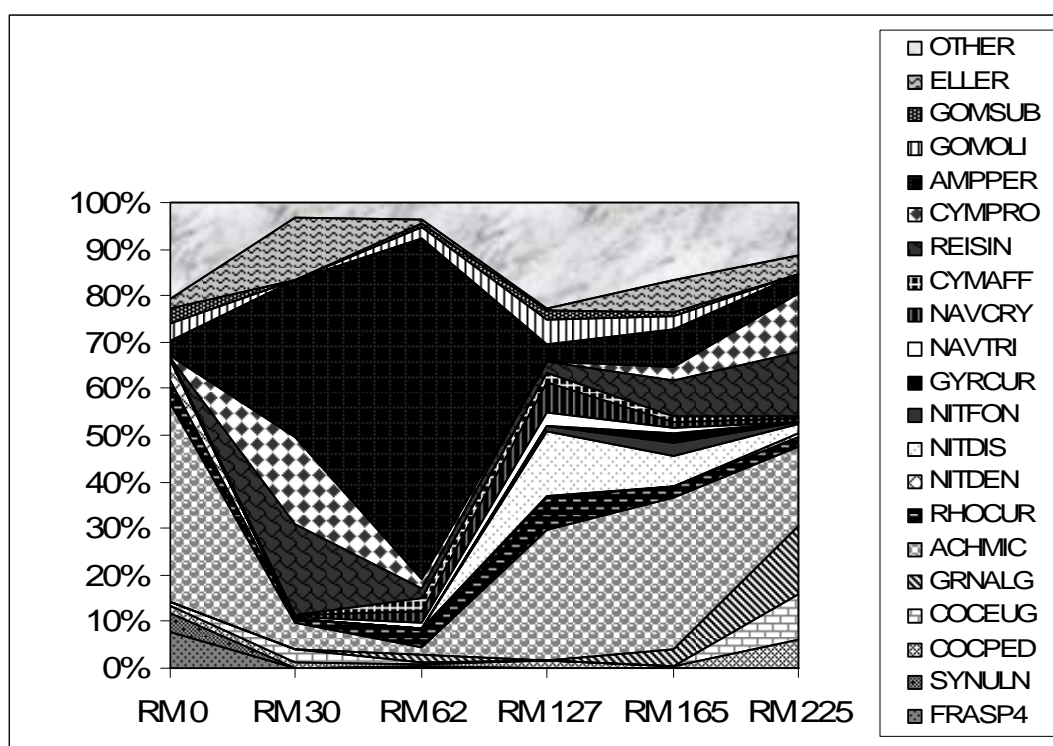


Figure 11. Area plot of dominant taxa (mean is $\geq 3\%$ of the assemblage) in epilithon at six sites downstream of the dam (see appendix B: Appendix 2.2 for abbreviations).

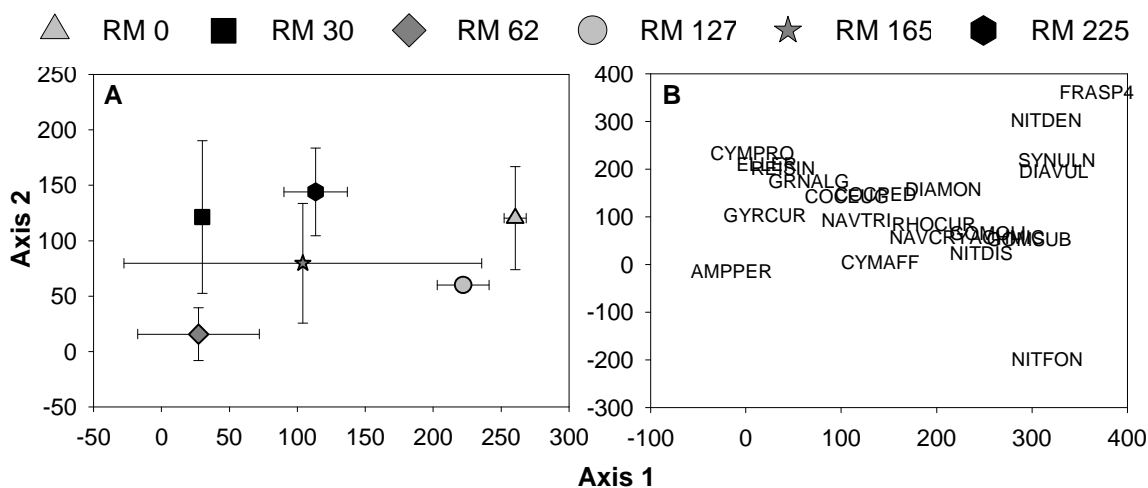


Figure 16. A) DCA ordination of mean (SD) sample scores for epilithon in January 2007 at six sites downstream of dam. Eigenvalues for axis 1 = 0.632; for axis 2 = 0.170. B) Corresponding species scores (see Appendix B: Appendix 15 for abbreviations).

Determination of epicremnon indicator species

DCA analysis of epicremnic algal assemblages at the six sites separated algal assemblages in the tailwaters from those downstream. Among downstream site assemblages separations also occurred, with RM 30 and 62 separating from RM 127, RM 165, and RM 225 (Figure 17). The tailwater assemblage separated from the downstream assemblages based on differences in the relative abundances of the following taxa: *Martyana martyi* (Héribaud) F.E. Round, *Cocconeis placentula* var. *euglypta* (Ehrenberg) Grunow, and *Fragilaria* sp. 4. River mile 30 separated from other downstream assemblages based on differences in the relative abundances of *E. arenaria* and *Pinnularia* sp. 1, and RM 62 separation was driven by green algae zoospores.

Examination of relative-abundance data of common epicremnic taxa (Figure 12) also allowed refinement of species indicator lists and more reach-specific (location shown parenthetically) downstream indicator taxa to be identified. These included: *Pinnularia* sp. 1 and *Encyonema auerswaldii* Rabenhorst (RM 30); green algae zoospores (RM 62); *N. tripunctata* and *Nitzschia palea* (Kützing) W. Smith (RM 127); *Melosira varians* C. Agardh and *Nitzschia kutzingiana* Hilse (RM 165); *Cymbella mexicana* (Ehr.) Cleve (RM 225); *N. dissipata* and *Synedra* sp. 1 (general downstream indicators).

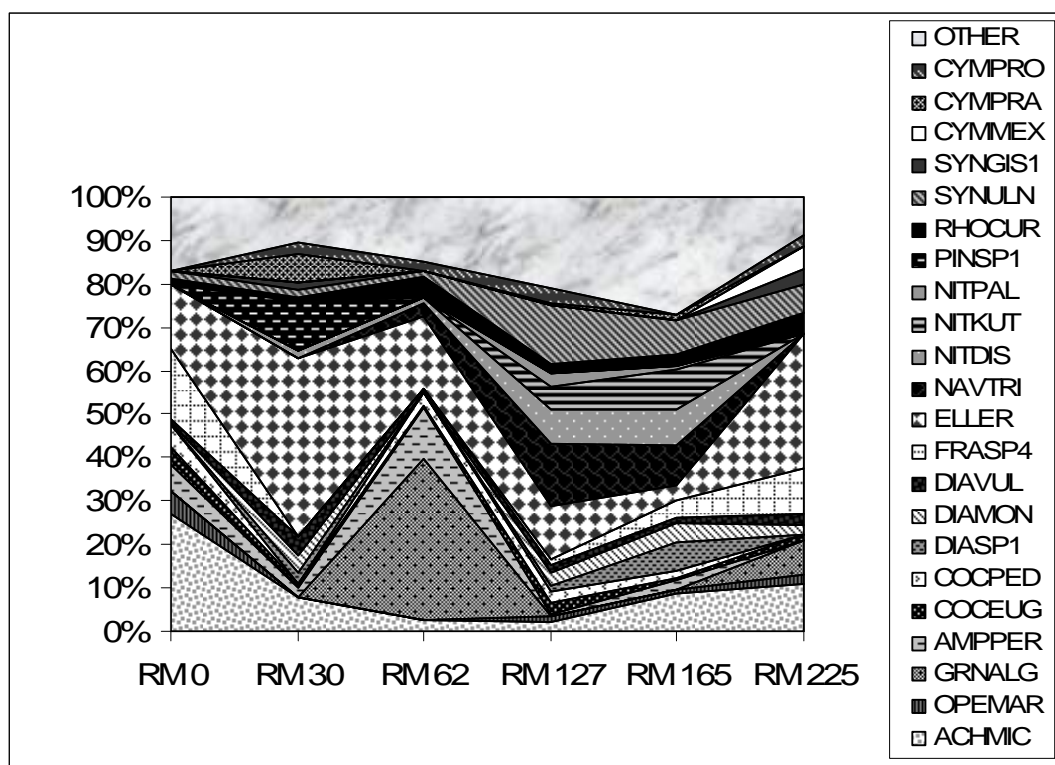


Figure 12. Area plot of dominant taxa (mean is $\geq 3\%$ of the assemblage) in epicremnon at six sites downstream of the dam (see appendix B: Appendix 2.2 for abbreviations).

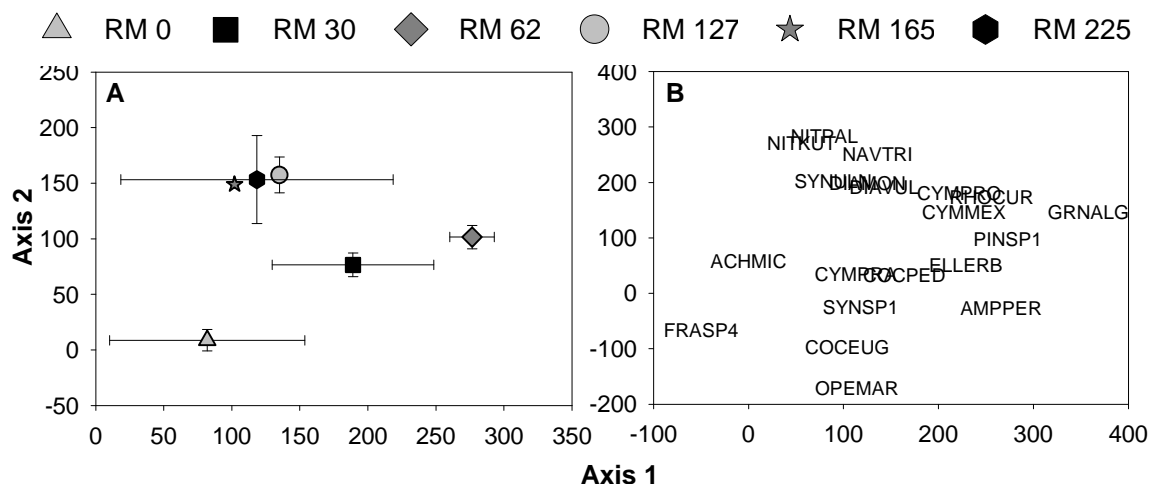


Figure 17. A) DCA ordination of mean (SD) samples scores for epicremnon in January 2007 at six sites downstream of dam. Eigenvalues for axis 1 = 0.461 ; for axis 2 = 0.272. B) Corresponding species scores (see Appendix B: Appendix 15 for abbreviations).

Overall, DCA and area plots were useful for identifying common taxa that contribute to assemblage differences and may be useful tailwater or downstream indicators. However, most of the taxa identified as possible indicators using this method were still present in both the tailwaters and at downstream sites. Therefore, when indicators were identified in macroinvertebrate diets it was impossible to conclude the original source of the species (i.e. tailwater versus downstream). Only four common taxa (*F. crotonensis*, *G. spencerii* et varieties, *N. kutzingiana*, *M. martyi*) identified using this method were included in the final indicator species list (Table 12). These common taxa were still determined to be useful indicators based on their relative abundance in the assemblage and dominance at sites. Specifically, *F. crotonensis* was still considered a useful tailwater indicator because it is the dominant planktonic diatom found in lower Lake Powell (Czarnecki and Blinn 1977) and in the tailwaters, and because generally *F. crotonensis* numbers progressively decline as distance from the dam increases. *M. martyi*, was also included because it comprises five percent of the tailwater epicremnon assemblage and was only found once at a downstream site during this study. *G. spencerii* et varieties and *N. kutzingiana* were still included as downstream indicators because they are only present at downstream sites and are never present in the tailwaters.

Rare taxa

Examining the prevalence of rare taxa (taxa that did not comprise greater than three percent of the algal assemblage, and therefore were excluded from the DCA and area plot analyses) was also useful for identifying tailwater and downstream indicators, and more rare taxa indicators were identified than dominant taxa indicators. Specifically,

the following three taxa were identified as tailwater indicators: *Amphora pediculus* (Kützing) Grunow ex A. Schmidt, *Brachysira vitrea* (Grunow) R. Ross, and *Diatoma tenue* var. *elongatum* Lyngbye, and the following seven taxa were identified as downstream indicators: *Nitzschia apiculata* (Gregory) Grunow, *Nitzschia* sp. 9, *Surirella ovalis* Brébisson, *Cymbella cymbiformis* var. *nonpunctata* Fontell, *Frustulia vulgaris* (Thwaites) De Toni, *Gyrosigma eximium* (Thwaites) Van Heurck, and *Craticula accomoda* (Hustedt) D.G. Mann (Table 12).

Final list and consumption by macroinvertebrates

The final indicator species list is a combination of the four dominant taxa and ten rare taxa (Table 12). Five taxa were identified as tailwater indicators and nine as downstream indicators (Table 12). Following final designation, each indicator was cross referenced with the algal assemblages of *S. arcticum* and *G. lacustris* diets to examine whether downstream macroinvertebrates eat tailwater and/or downstream algae. For example, if downstream *S. arcticum* diets contained taxa that were classified as tailwater indicators, then *S. arcticum* obtains some of their food resources from the tailwater. If *S. arcticum* also consumes downstream indicators, then they are also obtaining resources from downstream sites.

Table 12. Final list of tailwater and downstream algal indicators, the habitats they are indicators of, the sites where they are consumed by downstream macroinvertebrates, and the percent of production attributable to each indicator. Numbers in parentheses represent the percent of the community the indicator represented in the diet* and the percent of production attributable to each indicator**.

	Habitat indicator	Fuels downstream <i>S. arcticum</i>	Site where <i>S. arcticum</i> consumed taxa*	Percent of <i>S. arcticum</i> production attributable to indicator **	Fuels downstream <i>G. lacustris</i>	Site where <i>G. lacustris</i> consumed taxa*	Percent of <i>G. lacustris</i> production attributable to indicator**
Tailwater indicator							
<i>Fragilaria crotonensis</i>	Seston	YES	RM 0 (55.7) RM 30 (15.3) RM 62 (8.80) RM 127 (4.60) RM 165 (1.60) RM 225 (9.60)	RM 0 (33.5) RM 30 (5.92) RM 62 (3.00) RM 127 (1.32) RM 165 (0.42) RM 225 (3.67)	NO	RM 0 (7.20)	RM 0 (0.23)
<i>Amphora pediculus</i>	Epicremnon Epilithon	YES	RM 0 (0.07) RM 30 (0.20) RM 62 (0.09) RM 127 (0.14)	RM 0 (0.27) RM 30 (0.38) RM 62 (0.16) RM 127 (0.18)	NO	RM 0 (0.10)	RM 0 (0.34)
<i>Martyana martyi</i>	Epicremnon Epilithon	YES	RM 0 (0.09) RM 30 (0.35) RM 62 (0.32) RM 127 (0.21) RM 165 (1.70)	RM 0 (0.01) RM 30 (0.04) RM 62 (0.02) RM 127 (0.02) RM 165 (0.07)	NO	RM 0 (0.10)	RM 0 (0.01)
<i>Brachysira vitrea</i>	Epicremnon	YES	RM 0 (0.96) RM 165 (0.11) RM 225 (0.18)	RM 0 (0.38) RM 165 (0.02) RM 225 (0.04)	NO	RM 0 (3.35)	RM 0 (1.09)
<i>Diatoma tenue</i> var. <i>elongatum</i>	Epilithon	YES	RM 0 (0.18) RM 30 (0.51) RM 62 (0.30) RM 127 (0.14) RM 165 (0.32)	RM 0 (0.11) RM 30 (0.21) RM 62 (0.11) RM 127 (0.04) RM 165 (0.09)	YES	RM 30 (1.30) RM 127 (0.72)	RM 30 (0.28) RM 127 (0.18)
Downstream indicator							
<i>Nitzschia apiculata</i>	Seston	YES	RM 165 (0.37)	RM 165 (0.06)	NO	–	–
<i>Nitzschia kutzingiana</i>	Epicremnon Epilithon	YES	RM 165 (0.13)	RM 165 (0.02)	NO	–	–
<i>Nitzschia</i> sp. 9	Seston	NO	–	–	YES	RM 62 (0.31)	RM 62 (0.01)
<i>Surirella ovalis</i>	Seston	YES	RM 62 (2.05) RM 127 (0.14) RM 165 (0.52)	RM 62 (1.57) RM 127 (0.09) RM 165 (0.31)	YES	RM 165 (0.85)	RM 165 (0.47)
<i>Cymbella cymbiformis</i> var. <i>nonpunctata</i>	Seston	YES	RM 30 (0.08) RM 127 (0.07)	RM 30 (0.05) RM 127 (0.03)	YES	RM 30 (0.23)	RM 30 (0.08)
<i>Frustulia vulgaris</i>	Seston Epicremnon	YES	RM 62 (0.32) RM 225 (0.27)	RM 62 (0.13) RM 225 (0.13)	NO	–	–
<i>Gyrosigma eximium</i>	Epicremnon Epilithon	YES	RM 127 (0.93) RM 165 (0.39) RM 225 (0.22)	RM 127 (0.31) RM 165 (0.12) RM 225 (0.10)	YES	RM 30 (0.59) RM 62 (2.70) RM 225 (0.37)	RM 30 (0.12) RM 62 (1.76) RM 225 (0.11)
<i>Gyrosigma spencerii</i> et varieties	Epicremnon Epilithon	YES	RM 127 (0.20) RM 165 (0.10) RM 225 (0.54)	RM 127 (0.29) RM 165 (0.13) RM 225 (1.02)	NO	–	–
<i>Craticula accomoda</i>	Seston	YES	RM 165 (0.20)	RM 165 (0.03)	NO	–	–

Tailwater macroinvertebrates consumed tailwater indicators and downstream macroinvertebrates consumed both tailwater and downstream indicators. Of the five taxa identified as tailwater indicators, all five were consumed by macroinvertebrates in both the tailwaters and at downstream sites (Table 12); however, only the consumption of *F. crotonensis* by *S. arcticum* changed substantially. *Simulium arcticum* at downstream sites, contained tailwater indicators in their guts, though in low numbers. I estimated that in the tailwaters 34 percent of *S. arcticum* production is attributable to diatoms identified as tailwater indicators (Table 12, Figure 18). Of the tailwater indicators, *F. crotonensis* contributed the greatest amount to *S. arcticum* tailwater production (33 percent) (Table 12, Figure 18). At downstream sites, tailwater indicators contribute less than seven percent to downstream *S. arcticum* production, with *F. crotonensis* contributing the greatest amount to production (0.5 - 6 percent) amongst the five tailwater indicators (Table 12, Figure 18). The percent of *S. arcticum* production attributable to tailwater indicators is highest at RM 30 (6.5 percent), declining to less than 3.7 percent at all other downstream sites (Table 12, Figure 18). In addition, *S. arcticum* consumed species that were identified as seston indicators, but also consumed species that were identified as indicators of the epilithon/epicremnon (Table 12).

In contrast to *S. arcticum*, *G. lacustris* rarely had tailwater indicators in their guts at downstream sites. Tailwater indicators contributed to *G. lacustris* production at only two downstream sites (RM 30 and RM 127) (Table 12, Figure 19) and contributed the greatest amount to *G. lacustris* production at RM 30 (0.3 percent) (Table 12, Figure 19). *G. lacustris* also consumed species identified as seston and epilithon/epicremnon

indicators, and in general consumed more epilithic/epicremnic indicator species than seston indicator species.

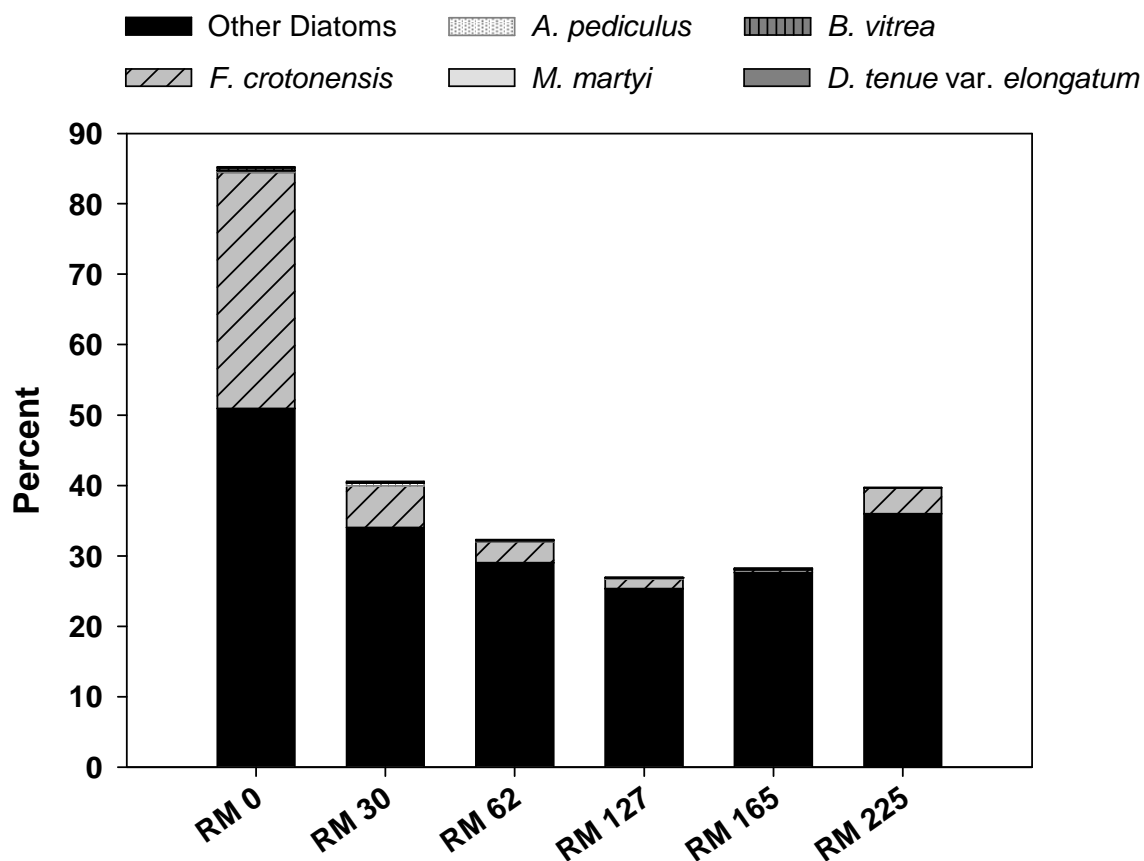


Figure 18. Percent of *S. arcticum* production attributable to tailwater indicator diatoms, and all other non-indicator diatoms, at six sites downstream of the dam.

S. arcticum consumed all five tailwater indicators at downstream sites; however, *G. lacustris* only consumed one tailwater indicator at a downstream site, *D. tenue* var. *elongatum*. *S. arcticum* consumed more of the downstream indicators at more sites than *G. lacustris*. *S. arcticum* consumed eight of the nine downstream indicators at downstream sites and *G. lacustris* consumed four.

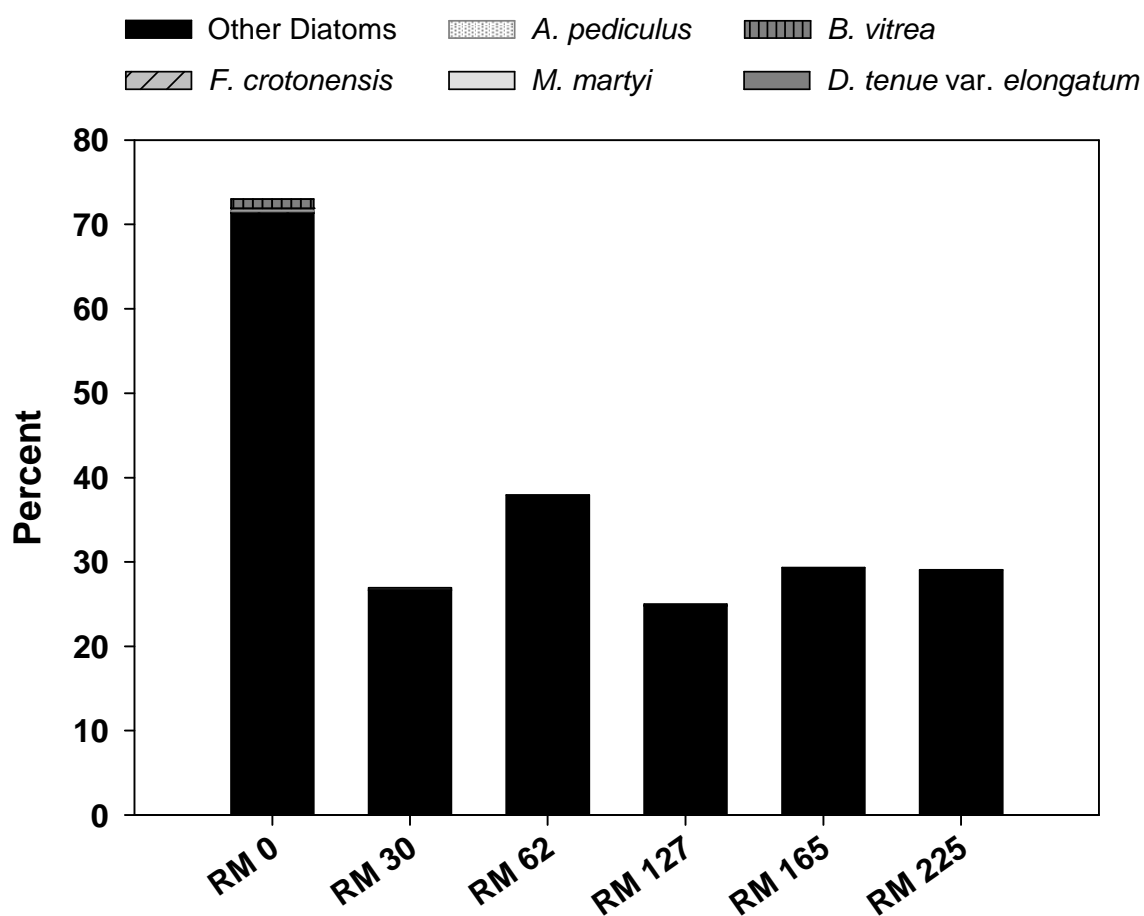


Figure 19. Percent of *G. lacustris* production attributable to tailwater indicator diatoms, and all other non-indicator diatoms, at six sites downstream of the dam.

Discussion

Summary of results

In this study, 167 algal species were observed, collectively, in the seston, epilithon, epicremnon and in diets of macroinvertebrates to examine the utility of employing a novel tracer to examine a resource subsidy. I identified a number of common and rare tracers and used these tracers to address a previously unanswered question. Results from this study provide evidence that tailwater (or reservoir) derived

algae are consumed by downstream macroinvertebrates, although tailwater indicators comprised less than 16 percent of diets and contributed less than 7 percent to macroinvertebrate production at downstream sites. Filter-feeding macroinvertebrates like *S. arcticum* are better suited to utilize upstream tailwater resources than scrapers such as *G. lacustris*, which feed more locally. This technique may have general applicability to other systems as well.

Algal downstream transport and survival

A euplanktonic species, *F. crotonensis*, was a useful indicator for this calculation, because the source is most likely from Lake Powell inputs, it is most common in the upper reaches, and its population is low throughout the canyon (Crayton and Sommerfeld 1979, Czarnecki and Blinn 1978). During downstream transport, mechanical destruction of plankton in the water column can occur via the grinding action of riffles and rapids laden with silt (Chandler 1937, Hartman and Himes 1961, Cushing 1964) and the decline in the average number of *F. crotonensis* dead cells may be due to degradation and destruction by rapids. In addition, because plankton can adhere to leaves and other suspended particles and debris; inputs of organic matter from tributaries may accelerate the settling and deposition of plankton onto the benthos (Chandler 1937). However, it is unlikely that deposition is responsible for observed patterns of longitudinal decline of *F. crotonensis*, as this taxon was rarely found in epilithic or epicremnic samples. In fact, the average number of live cells of *F. crotonensis* increases at RM 127. Despite the increase in live *F. crotonensis* cells at RM 127 and 165, this taxon comprised a small percentage of both seston and *S. arcticum* diets at downstream sites. The decline in sestonic

representation may have been due to: 1) degradation or deposition of *F. crotonensis* or, 2) dilution due to an increase in other diatoms from downstream sites or from epiphytes detaching from drifting *C. glomerata*.

The increase in live cells at RM 127 and RM 165 may be due to a number of factors: 1) there is a source population of *F. crotonensis* from a tributary above RM 127; 2) the live cells which survive through the rapids are reproducing downstream; 3) because we are sampling different pulses of water at each site (i.e. we are not tracking the same pulse of water) there may have been more live *F. crotonensis* cells transported from the tailwaters in the pulse of water we sampled at those sites. In addition, because daily discharge fluctuates in this system, increased discharge on some days may increase the transport distance of plankton from lake outlets (Ward 1975, Armitage and Capper 1976, Vadeboncoeur 1994). The increase in live cells suggests *F. crotonensis* is capable of reproducing downstream or there are tributary source populations of *F. crotonensis*; however, there is little evidence to support these hypotheses. *F. crotonensis* is a euplanktonic diatom that is present in Lake Powell (Czarnecki and Blinn 1978) and dominates the seston community in the tailwaters but not downstream. The phytoplankton population in the river is dominated by tychoplankters (periphytic organisms that become entrained in the water column due to turbulence, sloughing of the filamentous algae to which they are attached, etc.) and few euplanktonic (organisms that spend most or all of their lives as plankton) species, besides *F. crotonensis*, are present in the river (Crayton and Sommerfeld 1979). Therefore, the likelihood of a source population from one of the low discharge tributaries seems low especially because *F.*

crotonensis is typically planktonic, and there are not significant lakes and dams in tributaries. The lakes and dams that are in tributaries are high in the watershed and are connected to the mainstem only during times of extreme flooding. Furthermore, no source population from tributaries has been reported. Extensive sampling of tributary seston algal assemblages would help to clarify the source of live cells at downstream sites. Turbidity, low water temperatures, high current velocity, and high variability in water levels may also inhibit the production of euplanktonic diatoms at downstream sites (Crayton and Sommerfeld 1979). Crayton and Sommerfeld (1979) concluded there is insufficient time for reproduction of plankton in the Colorado River due to the high flow and short travel time of water through the canyon (ca. 3-4 days from Lake Powell to Lake Mead); therefore, reproduction of *F. crotonensis* downstream seems unlikely. The sampling of different pulses of water, with potentially different starting concentrations of live *F. crotonensis* cells, at each site, may be the most plausible explanation for the increase.

The decline in *F. crotonensis* provides evidence that the transport of phytoplankton progressively declines as distance downstream increases, and tailwater/lake resource use by macroinvertebrates also declines (Figure 6). A number of studies document the decline of zooplankton (Ward 1975, Armitage and Capper 1976, Sandlund 1982, Palmer and O’Keeffe 1990, Walks and Cyr 2004) and phytoplankton (Maciolek and Tunzi 1968, Walks and Cyr 2004, Sabater et al. 2008) as distance downstream from lakes or reservoirs increases. Likewise, recent food web studies using stable isotopes, document that the importance of reservoir plankton subsidies to

downstream food webs declines with downstream distance from reservoirs (Doi et al. 2008, Mercado-Silva et al. 2008). Doi et al. 2008, estimated that zooplankton released from Kanogawa Dam contributed significantly (from 20 -100 percent) to the diets of collector-filterer macroinvertebrate diets 0.2 km below the dam, but within 10 km contribution to macroinvertebrate diets decreased substantially (from 0 - 40 percent).

A number of factors can influence the downstream transport of particles and plankton including mechanical degradation, destruction and sedimentation (Chandler 1937, Hartman and Himes 1961, Cushing 1964, Ward 1975), and removal by filter-feeding organisms (Richardson and Mackay 1991, Monaghan et al. 2001) and aquatic plants such as macrophytes (Chandler 1937, Horvath 2004). Hydrologic variables such as discharge, turbulence, water depth and velocity (Wollheim et al. 2001, Hall et al. 1996, Thomas et al. 2001) can also influence seston particle transport and deposition and lake-outlet studies document that reservoir plankton are transported and persist further downstream as discharge increases (Ward 1975, Armitage and Capper 1976, Vadeboncoeur 1994).

In this study I estimated the expected transport distance before deposition (S_p) of a tailwater diatom in the Colorado River to be 15.5 miles. Deposition velocity (V_{dep}) was also calculated because it eliminates the scaling effect of depth and velocity on transport distance (Thomas et al. 2001) and allows for comparison among streams with varying water depths and velocities (i.e. discharge). *F. crotonensis* ranges in size from 40-170 μm . In comparison to studies with similar particle size ranges (15-1000 μm) the V_{dep} (0.24 mm s^{-1}) of *F. crotonensis* was similar to those reported elsewhere. Specifically, in a

first-order Idaho creek the diatom *Asterionella* ($>52\ \mu\text{m}$) had a V_{dep} of $0.99\ \text{mm s}^{-1}$ (Thomas et al. 2001), fine particulate organic matter ($<1\ \text{mm}$) V_{dep} was $0.07\text{--}0.16\ \text{mm s}^{-1}$ in second and third-order Idaho streams (Cushing et al. 1993), and settling velocity (comparable to V_{dep}) of corn pollen ($43\text{--}105\ \mu\text{m}$) was $0.263\text{--}0.311\ \text{mm s}^{-1}$ in a second-order stream in New York (Miller and Georgian 1992). Because the V_{dep} of *F. crotonensis* is similar to the measured depositional velocities of other similar sized particles, the estimated transport distance (S_p) of 15.5 miles seems accurate for this system. Furthermore the V_{dep} estimate corresponds with the trends displayed in Figures 5 and 6, showing the greatest decline in *F. crotonensis* occurring in the first 30 miles, in both the seston and *S. arcticum* diets.

The short transport distance of *F. crotonensis*, also provides evidence that tailwater primary production may not effectively fuel the downstream food web. The decline in *F. crotonensis* may be indicative of the declines that may be expected for other tailwater diatoms. The low proportion of *F. crotonensis* in *S. arcticum* diets, demonstrates the importance of diatoms produced at downstream sites, rather than those transported from upstream, as a resource for filter-feeders. In addition, *G. lacustris* consumed species identified as seston and epilithon/epicremnon indicators, demonstrating that diatoms in the seston can be deposited on the benthos and consumed by macroinvertebrates. However, *F. crotonensis* was only consumed by *G. lacustris* in the tailwaters; therefore, the potential for other tailwater diatoms to be transported downstream, deposited, and frequently consumed by macroinvertebrates seems unlikely.

Macroinvertebrate consumption of indicators

Tailwaters as a subsidy

Addressing the extent that tailwater primary production supports downstream macroinvertebrate production requires the use of a tracer. Using tailwater and downstream indicator species and measuring the extent to which macroinvertebrates consume these species, I conclude that downstream macroinvertebrates rely on a combination of tailwater and downstream food resources, including diatoms produced within tributaries. Seston from reservoirs can be an important food resource for consumers, particularly for collector-filterers, downstream of dams (Elliott and Corlett 1972, Petts 1984, Richardson 1984, Richardson and Mackay 1991, Voelz and Ward 1996, Doi et al. 2008). Of note, I found that *S. arcticum* consumed more tailwater indicators at downstream sites than *G. lacustris*, suggesting that the extent that tailwater resources can subsidize downstream macroinvertebrates depends on the functional feeding groups present in the system (Doi et al 2008). *S. arcticum* is a collector-filterer and can trap very small particles (Wotton 1976, Wotton 1977, Wallace and Merritt 1980), planktonic species and tychoplankters that are sloughed from the epilithon or epicremnon are accessible to these macroinvertebrates. In contrast, *G. lacustris*, a shredder, can only consume species that are deposited on the benthos, and planktonic and tailwater algae sloughed from the benthos and transported downstream may not be accessible. *S. arcticum* consumed eight of the nine downstream indicators at downstream sites and *G. lacustris* consumed four. Six of the downstream indicators were identified as seston indicators and five were identified as epilithic/epicremnic indicators (Table 12) (note

total number of downstream habitat indicators does not equal nine because some species were identified as indicators of both the seston and epilithon/epicremnon), again indicating that tailwater and tributary resources may be a more important subsidy for filter-feeding macroinvertebrates than shredders.

Consumption of downstream indicator taxa confirms the importance of downstream resources in the diets of macroinvertebrates. It seems unlikely that downstream macroinvertebrates are obtaining most of their resources from tailwater primary production because tailwater indicator species are rarely consumed or are consumed in extremely low proportions, and rare taxa that only grow downstream are also consumed, even though they are not the dominant taxa present downstream. I estimated that less than seven and 0.3 percent of *S. arcticum* and *G. lacustris* production, respectively, may be attributable to tailwater indicators at downstream sites. This estimate suggests that the tailwaters may not provide a significant resource subsidy to downstream macroinvertebrate communities. Some macroinvertebrate production may be derived from algal exudates or amorphous detritus derived from algae (Hart and Lovvorn 2003), but I estimated that autochthonously derived amorphous detritus contributed less than eleven percent to macroinvertebrate production at downstream sites (Chapter 1).

DCA, area plots and rare taxa analysis for indicator identification

DCA, area plots, and analysis of the occurrence of rare taxa were useful for identifying species that could be used as tailwater and downstream indicators. More rare taxa were ultimately identified as indicators than dominant taxa, because dominant taxa were often prevalent in both the tailwaters and downstream sites. In addition, more rare

taxa indicators were initially identified, but were ultimately discarded because their presence was so infrequent or low that they were never consumed by macroinvertebrates. Additional analyses of macroinvertebrate and habitat samples may allow for more rare taxa to be utilized as indicators in the future.

Indicator presence and preferences

Five species were identified as tailwater indicators and, of these five, only two, *B. vitrea* and *D. tenue* var. *elongatum*, were found solely in the tailwaters. The other three taxa, *F. crotonensis*, *A. pediculus*, and *M. martyi* were also present at downstream sites; however, *A. pediculus* and *M. martyi* were only present at one site in extremely low proportions, and therefore were still considered tailwater indicators. *B. vitrea* and *A. pediculus* have also previously been reported at downstream sites (Czarnecki and Blinn 1978). *B. vitrea* has been reported in Clear and Diamond Creeks, but is also found in lower Lake Powell. *A. pediculus* has been reported in epiphytic collections throughout the canyon (in low numbers), but is known to prefer filamentous algae or large diatoms as a substrate, which may explain their preference for the tailwaters in these samples (Patrick and Reimer 1966, Czarnecki and Blinn 1978). *F. crotonensis* and *D. tenue* var. *elongatum* appear to be the best tailwater indicators; however, analyzing more samples from other seasons may help to identify additional tailwater indicators.

Nine taxa were identified as downstream indicators. Eight of these nine were identified to species level and their ecological preferences reflected the change from clear (tailwaters) to turbid (downstream) water conditions. *C. accomoda* thrives in the presence of high organics (Patrick and Reimer 1966) and has been previously collected from

epipellic and psammon collections (which tend to be higher in organics than the epilithon) in Kanab and Bright Angel Creek (Czarnecki and Blinn 1978). *C. cymbiformis* var. *nonpunctata* has only been previously collected in epilithic samples (these collections were associated with fine particulate material) of Elves Chasm (RM 116.5) (Czarnecki and Blinn 1978). *S. ovalis* is an epipellic species found in the Little Colorado River (although it also has been reported from the Lake Powell area) (Czarnecki and Blinn 1978, Kelly et al. 2005). In my samples, *S. ovalis* was not collected until downstream of the confluence with the Little Colorado River. Because this taxon is consumed by macroinvertebrates in the mainstem, it confirms that tributary resources are used by downstream macroinvertebrates; however, this taxon contributes less than two percent to macroinvertebrate production at downstream sites (Table 12). *Gyrosigma* spp. are also typically epipellic (Kelly et al 2005) and therefore do well at downstream sites. *N. kutzingiana* and *N. apiculata* have been reported to be common in lower Lake Powell and throughout the Colorado River system of the Grand Canyon and may not be appropriate to use as downstream indicators (Czarnecki and Blinn 1978). *F. vulgaris* is also reported to be common throughout the system (Czarnecki and Blinn 1978), but it has never been observed in Lake Powell and has only been collected downstream in our samples. In conclusion, *C. accomoda*, *C. cymbiformis* var. *nonpunctata*, *S. ovalis*, *F. vulgaris* and *Gyrosigma* spp. may serve as the best downstream indicators in this system.

Utility of the method/usefulness of algae as indicators/tracers

This method was useful for examining the consumption of tailwater algal taxa by downstream macroinvertebrates and helped to address whether downstream food webs

are fueled by autochthonous resources produced in the tailwaters (Carothers and Brown 1991). Assessing differences using the dominant taxa in the system established that algal assemblages at each site were not sufficiently different to distinguish among the downstream sites, but were useful for distinguishing between the tailwaters and downstream. Downstream assemblages did differ from the tailwater assemblages; however, because the taxa that drove the differences were common throughout the system, few were determined to be useful indicators (tracers). Rare taxa were better indicators because of their ecological preferences and specificity to tailwater or downstream sites.

Although this method helped to address an important question relating to an ecological subsidy, the required algal community analyses to the species level in a system with high algal species diversity, resulted in an extremely time-consuming process. In addition, this method can only be used in systems where there are community differences among sites and therefore species can be classified as site-specific indicators. The physical and chemical conditions in the Colorado River differ among the tailwaters and downstream sites and I was able to identify useful indicators. In more uniform systems, it may be difficult to identify indicators; therefore, using algae as tracers may only be useful in some systems. Other tracer techniques may be employed to further examine the extent to which the tailwaters provide an ecological subsidy to downstream food webs. For example, diatoms labeled with ^{14}C sodium bicarbonate were used to examine seston transport and deposition in Idaho streams (Thomas et al. 2001), and fluorescently labeled bacteria (FLB) were used to examine bacterial transport and consumption by

macroinvertebrates in a second-order stream in North Carolina (Hall et al. 1996).

Although both of these methods were used in streams much smaller than the Colorado River, exploring the potential use of labeled particles to address the importance of tailwater and reservoir subsidies to downstream systems may be valuable.

Conclusion

In conclusion, primary production in tailwaters (or upstream reservoirs) of rivers may subsidize downstream macroinvertebrates; however, the importance of the subsidy may decline with distance downstream from the dam. The suggestion that the highly productive tailwaters below Glen Canyon Dam serve as a resource subsidy to downstream food webs is partially correct, because downstream macroinvertebrates consume algae produced in the tailwaters. However, macroinvertebrates also consume algae produced at downstream sites and tailwaters indicators were estimated to contribute less than seven percent to downstream macroinvertebrate production. Furthermore, algae produced in the tailwaters of the dam or lake are capable of being transported downstream, but their numbers and dominance in the community decline as distance from the tailwater increases.

I also estimated the transport distance of planktonic diatoms or diatoms sloughed into the seston is 15.5 miles (25 km); therefore, most of the production exported from tailwaters may not be transported far enough and in a form that can fuel macroinvertebrate production throughout the 226 mile (363 km) stretch of river through the Grand Canyon. Macroinvertebrates are an important food resource for fish (Childs et al. 1998, Zahn et al. unpublished data), and an important goal of scientists and managers

in this system is to better manage dam operations to increase and support native fish production, particularly the endangered humpback chub. The largest and only successfully reproducing population of humpback chub in the Canyon is located near the confluence of the Colorado and Little Colorado Rivers, 61 miles downstream from the dam (Gloss and Coggins 2005). Because tailwater primary production may only serve as an important subsidy up to 15.5 miles downstream of the dam, macroinvertebrates and native fish at downstream sites may be supported by other food resources, and managing the system to maximize access to these resources may be an important task.

APPENDIX A
ONE-WAY ANOVA TABLES

Appendix 1. One-way ANOVA p -values for suspended organic seston between sites by season. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0125 . NS indicates non-significant p -value.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Summer	Diatoms	df:5,8 F:9.9					
		RM 30	0.820	-	-	-	-
		RM 62	0.130	0.724	-	-	-
		RM 127	0.008	0.257	0.979	-	-
		RM 165	0.003	0.104	0.737	0.911	-
Summer	A. Detritus	RM 225	0.007	0.231	0.965	1.000	0.946
		df:5,8 F:3.0					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
Summer	Leaves	RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
		df:5,8 F:2.6					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
Summer	Fila. Algae	RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
		df:5,8 F:0.5					
		RM 30	NS	-	-	-	-
Autumn	Diatoms	RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
		df:5,12 F:26.2					
Autumn	A. Detritus	RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.048	-	-	-
		RM 127	< 0.001	0.281	0.864	-	-
		RM 165	< 0.001	0.091	0.999	0.973	-
		RM 225	< 0.001	0.572	0.552	0.990	0.767
Autumn	Leaves	df:5,12 F:38.4					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.954	-	-	-
		RM 127	< 0.001	0.921	1.000	-	-
		RM 165	< 0.001	0.059	0.014	0.012	-
Autumn	Fila. Algae	RM 225	< 0.001	0.176	0.534	0.605	0.001
		df:5,12 F:10.4					
		RM 30	0.110	-	-	-	-
		RM 62	0.002	0.223	-	-	-
		RM 127	0.002	0.239	1.000	-	-
Autumn	Fila. Algae	RM 165	0.119	1.000	0.208	0.223	-
		RM 225	0.001	0.056	0.946	0.933	0.051
		df:5,12 F:2.9					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
Autumn	Fila. Algae	RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
		df:5,12 F:2.9					
		RM 30	NS	-	-	-	-

Appendix 1. Continued.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Winter	Diatoms	df:5,12 F:40.2					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.287	-	-	-
		RM 127	< 0.001	0.036	0.771	-	-
		RM 165	< 0.001	0.005	0.207	0.849	-
Winter	A. Detritus	RM 225	< 0.001	0.104	0.982	0.985	0.499
		df:5,12 F:9.8					
		RM 30	0.188	-	-	-	-
		RM 62	0.024	0.804	-	-	-
		RM 127	0.003	0.168	0.750	-	-
Winter	Leaves	RM 165	0.001	0.040	0.290	0.944	-
		RM 225	0.003	0.164	0.741	1.000	0.948
		df:5,12 F:1.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
Winter	Fila. Algae	RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
		df:5,12 F:2.4					
		RM 30	NS	-	-	-	-
Spring	Diatoms	RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
		df:5,11 F:6.3					
Spring	A. Detritus	RM 30	0.773	-	-	-	-
		RM 62	0.004	0.034	-	-	-
		RM 127	0.199	0.826	0.219	-	-
		RM 165	0.071	0.463	0.513	0.982	-
		RM 225	0.035	0.216	0.960	0.735	0.965
Spring	Leaves	df:5,11 F:7.3					
		RM 30	0.925	-	-	-	-
		RM 62	0.007	0.029	-	-	-
		RM 127	0.430	0.911	0.142	-	-
		RM 165	0.011	0.050	0.999	0.230	-
Spring	Fila. Algae	RM 225	0.049	0.182	0.968	0.563	0.996
		df:5,11 F:9.7					
		RM 30	0.981	-	-	-	-
		RM 62	0.169	0.059	-	-	-
		RM 127	0.011	0.004	0.541	-	-
Spring	Leaves	RM 165	0.909	0.570	0.597	0.054	-
		RM 225	0.008	0.003	0.314	0.985	0.034
		df:5,11 F:1.9					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
Spring	Fila. Algae	RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Appendix 2. One-way ANOVA p -values for suspended organic seston between seasons by site. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0083. NS indicates non-significant p -value. N/A indicates no data available.

Site	Food Resource	Season	Summer	Autumn	Winter
RM 0	Diatoms	df:3,8 F:1.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	A. Detritus	df:3,8 F:6.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	Leaves	df:3,8 F:1.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	Fila. Algae	df:3,8 F:1.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Diatoms	df:3,6 F:19.8			
		Autumn	0.100	-	-
		Winter	0.165	0.935	-
RM 30	A. Detritus	df:3,6 F:37.0			
		Autumn	0.041	-	-
		Winter	0.831	0.029	-
RM 30	Leaves	df:3,6 F:3.3			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Fila. Algae	df:3,6 F:1.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Diatoms	df:3,6 F:22.7			
		Autumn	0.014	-	-
		Winter	0.202	0.060	-
RM 62	A. Detritus	df:3,6 F:1.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,6 F:3.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,6 F:2.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62		Spring	NS	NS	NS

Appendix 3. One-way ANOVA p -values for epilithon between sites by season. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0125 . NS indicates non-significant p -value.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Summer	Diatoms	df:5,12 F:3.4					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Summer	A. Detritus	df:5,12 F:5.7					
		RM 30	0.693	-	-	-	-
		RM 62	0.089	0.594	-	-	-
		RM 127	0.081	0.668	1.000	-	-
		RM 165	0.069	0.616	1.000	1.000	-
		RM 225	0.004	0.068	0.825	0.571	0.623
Summer	Leaves	df:5,12 F:4.5					
		RM 30	0.155	-	-	-	-
		RM 62	0.457	0.997	-	-	-
		RM 127	0.007	0.509	0.376	-	-
		RM 165	0.080	0.999	0.964	0.728	-
		RM 225	0.133	1.000	0.994	0.561	1.000
Summer	Fila. Algae	df:5,12 F:16.5					
		RM 30	< 0.001	-	-	-	-
		RM 62	0.001	1.000	-	-	-
		RM 127	< 0.001	1.000	1.000	-	-
		RM 165	< 0.001	1.000	1.000	1.000	-
		RM 225	< 0.001	1.000	1.000	1.000	1.000
Autumn	Diatoms	df:5,11 F:2.8					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Autumn	A. Detritus	df:5,11 F:6.7					
		RM 30	0.011	-	-	-	-
		RM 62	0.026	1.000	-	-	-
		RM 127	0.003	0.961	0.961	-	-
		RM 165	0.040	0.959	0.985	0.604	-
		RM 225	0.214	0.452	0.609	0.152	0.879
Autumn	Leaves	df:5,11 F:1.1					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Autumn	Fila. Algae	df:5,11 F:1.4					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Site	Food Resource	Season			
RM 0	Diatoms	df:3,9 F:1.1	Summer	Autumn	Winter
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 0	A. Detritus	df:3,9 F:4.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 0	Leaves	df:3,9 F:6.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 0	Fila. Algae	df:3,9 F:1.3			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 30	Diatoms	df:3,8 F:9.5			
		Autumn	0.024	-	-
		Winter	0.092	0.768	-
		Spring	0.833	0.008	0.028
RM 30	A. Detritus	df:3,8 F:12.8			
		Autumn	0.003	-	-
		Winter	0.089	0.120	-
		Spring	0.998	0.004	0.114
RM 30	Leaves	df:3,8 F:7.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 30	Fila. Algae	df:3,8 F:1.0			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 62	Diatoms	df:3,6 F:4.1			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 62	A. Detritus	df:3,6 F:5.9			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 62	Leaves	df:3,6 F:3.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 62	Fila. Algae	df:3,6 F:1.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS

Appendix 5. One-way ANOVA p -values for epicremnon between sites by season. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0125. NS indicates non-significant p -value.

Season	Food Resource	Site					
Summer	Diatoms	df:5,9 F:22.8	RM 0	RM 30	RM 62	RM 127	RM 165
		RM 30	0.998	-	-	-	-
		RM 62	0.759	0.922	-	-	-
		RM 127	0.002	0.008	0.140	-	-
		RM 165	0.001	0.002	0.038	0.779	-
		RM 225	< 0.001	0.001	0.012	0.238	0.854
Summer	A. Detritus	df:5,9 F:13.1					
		RM 30	0.463	-	-	-	-
		RM 62	0.121	1.000	-	-	-
		RM 127	0.002	0.409	0.578	-	-
		RM 165	0.005	0.515	0.670	1.000	-
		RM 225	0.001	0.201	0.357	0.985	0.946
Summer	Leaves	df:5,9 F:6.5					
		RM 30	0.493	-	-	-	-
		RM 62	0.749	0.997	-	-	-
		RM 127	0.018	0.509	0.376	-	-
		RM 165	0.025	0.999	0.964	0.728	-
		RM 225	0.008	1.000	0.994	0.561	1.000
Summer	Fila. Algae	df:5,9 F:61.5					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	1.000	-	-	-
		RM 127	< 0.001	1.000	1.000	-	-
		RM 165	< 0.001	1.000	1.000	1.000	-
		RM 225	< 0.001	1.000	1.000	1.000	1.000
Autumn	Diatoms	df:5,10 F:11.4					
		RM 30	0.327	-	-	-	-
		RM 62	0.899	0.995	-	-	-
		RM 127	0.001	0.026	0.069	-	-
		RM 165	0.011	0.276	0.342	0.621	-
		RM 225	0.002	0.034	0.082	1.000	0.711
Autumn	A. Detritus	df:5,10 F:8.2					
		RM 30	0.086	-	-	-	-
		RM 62	0.629	0.986	-	-	-
		RM 127	0.011	0.758	0.630	-	-
		RM 165	0.011	0.749	0.623	1.000	-
		RM 225	0.002	0.143	0.186	0.709	0.718
Autumn	Leaves	df:5,10 F:1.5					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Autumn	Fila. Algae	df:5,10 F:0.5					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Appendix 5. Continued.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Winter	Diatoms	df:5,12 F:2.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
Winter	A. Detritus	df:5,12 F:0.8					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
Winter	Leaves	df:5,12 F:7.5					
		RM 30	0.001	-	-	-	-
		RM 62	0.012	0.705	-	-	-
		RM 127	0.015	0.634	1.000	-	-
		RM 165	0.006	0.898	0.998	0.994	-
Winter	Fila. Algae	df:5,12 F:1.7					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
Spring	Diatoms	df:5,12 F:4.1					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
Spring	A. Detritus	df:5,12 F:3.2					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
Spring	Leaves	df:5,12 F:3.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
Spring	Fila. Algae	df:5,12 F:0.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Appendix 6. One-way ANOVA *p*-values for epicremnon between seasons by site. Numbers in bold reflect values with a bonferonni corrected *p*-value < 0.0083. NS indicates non-significant *p*-value.

Site	Food Resource	Season	Summer	Autumn	Winter
RM 0	Diatoms	df:3,8 F:1.9			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	A. Detritus	df:3,8 F:3.9			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	Leaves	df:3,8 F:3.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	Fila. Algae	df:3,8 F:1.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Diatoms	df:3,7 F:8.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	A. Detritus	df:3,7 F:11.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Leaves	df:3,7 F:7.1			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Fila. Algae	df:3,7 F:0.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Diatoms	df:3,4 F:14.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	A. Detritus	df:3,4 F:2.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,4 F:4.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,4 F:0.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS

Appendix 6. Continued.

Site	Food Resource	Season	Summer	Autumn	Winter
RM 127	Diatoms	df:3,8 F:2.7			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	A. Detritus	df:3,8 F:2.7			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	Leaves	df:3,8 F:0.9			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	Fila. Algae	df:3,8 F:0.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 165	Diatoms	df:3,8 F:1.3			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 165	A. Detritus	df:3,8 F:2.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 165	Leaves	df:3,8 F:11.6			
		Autumn	0.007	-	-
		Winter	0.999	0.006	-
		Spring	0.043	0.543	0.036
RM 165	Fila. Algae	df:3,8 F:0.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 225	Diatoms	df:3,8 F:10.1			
		Autumn	0.874	-	-
		Winter	0.287	0.653	-
		Spring	0.004	0.010	0.052
RM 225	A. Detritus	df:3,8 F:3.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 225	Leaves	df:3,8 F:14.3			
		Autumn	0.001	-	-
		Winter	0.082	0.027	-
		Spring	0.029	0.075	0.876
RM 225	Fila. Algae	df:3,8 F:1.0			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS

Appendix 7. One-way ANOVA p -values for *Simulium arcticum* between sites by season. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0125 . NS indicates non-significant p -value. N/A indicates no data available.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Summer	Diatoms	df:5,18 F:43.2					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.206	-	-	-
		RM 127	< 0.001	0.002	0.217	-	-
		RM 165	< 0.001	< 0.001	0.027	0.867	-
		RM 225	< 0.001	0.055	0.976	0.580	0.110
Summer	A. Detritus	df:5,18 F:46.4					
		RM 30	0.001	-	-	-	-
		RM 62	< 0.001	0.001	-	-	-
		RM 127	< 0.001	< 0.001	0.789	-	-
		RM 165	< 0.001	< 0.001	0.384	0.979	-
		RM 225	< 0.001	< 0.001	0.955	0.998	0.855
Summer	Leaves	df:5,18 F:4.1					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Summer	Fila. Algae	df:5,18 F:0.8					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Autumn	Diatoms	df:5,18 F:58.3					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.837	-	-	-
		RM 127	< 0.001	0.920	0.301	-	-
		RM 165	< 0.001	1.000	0.936	0.811	-
		RM 225	< 0.001	1.000	0.802	0.941	0.999
Autumn	A. Detritus	df:5,18 F:50.4					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.820	-	-	-
		RM 127	< 0.001	0.720	0.139	-	-
		RM 165	< 0.001	0.036	0.003	0.415	-
		RM 225	< 0.001	1.000	0.769	0.774	0.044
Autumn	Leaves	df:5,18 F:5.8					
		RM 30	0.952	-	-	-	-
		RM 62	0.965	1.000	-	-	-
		RM 127	0.317	0.796	0.764	-	-
		RM 165	0.002	0.011	0.010	0.139	-
		RM 225	0.956	1.000	1.000	0.788	0.011
Autumn	Fila. Algae	df:5,18 F:0.7					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Appendix 7. Continued.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Winter	Diatoms	df:5,18 F:8.9					
		RM 30	0.003	-	-	-	-
		RM 62	< 0.001	0.932	-	-	-
		RM 127	< 0.001	0.933	1.000	-	-
		RM 165	0.001	0.985	1.000	1.000	-
Winter	A. Detritus	df:5,18 F:3.7					
		RM 225	0.001	0.999	0.994	0.994	1.000
		RM 30	0.293	-	-	-	-
		RM 62	0.014	0.597	-	-	-
		RM 127	0.100	0.987	0.917	-	-
Winter	Leaves	df:5,18 F:3.1					
		RM 165	0.764	0.954	0.186	0.679	-
		RM 225	0.062	0.944	0.975	1.000	0.526
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
Winter	Fila. Algae	df:5,18 F:1.7					
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
		RM 30	NS	-	-	-	-
Spring	Diatoms	df:4,12 F:34.4					
		RM 62	< 0.001	N/A	-	-	-
		RM 127	< 0.001	N/A	0.766	-	-
		RM 165	< 0.001	N/A	0.993	0.617	-
		RM 225	< 0.001	N/A	0.607	0.999	0.379
Spring	A. Detritus	df:4,12 F:20.7					
		RM 30	N/A	N/A	-	-	-
		RM 62	< 0.001	N/A	-	-	-
		RM 127	0.001	N/A	0.787	-	-
		RM 165	< 0.001	N/A	1.000	0.782	-
Spring	Leaves	df:4,12 F:1.1					
		RM 225	< 0.001	N/A	0.942	0.961	0.937
		RM 30	N/A	N/A	-	-	-
		RM 62	NS	N/A	-	-	-
		RM 127	NS	N/A	NS	-	-
Spring	Fila. Algae	df:4,12 F:0.4					
		RM 165	NS	N/A	NS	NS	-
		RM 225	NS	N/A	NS	NS	NS
		RM 30	N/A	N/A	-	-	-
		RM 62	NS	N/A	-	-	-
Spring	Fila. Algae	df:4,12 F:0.4					
		RM 127	NS	N/A	NS	-	-
		RM 165	NS	N/A	NS	NS	-
		RM 225	NS	N/A	NS	NS	NS
		RM 30	N/A	N/A	-	-	-

Appendix 8. One-way ANOVA p -values for *Simulium arcticum* between seasons by site. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0083 . NS indicates non-significant p -value. N/A indicates no data available.

Site	Food Resource	Season			
RM 0	Diatoms	df:3,12 F:4.8	Summer	Autumn	Winter
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	A. Detritus	df:3,12 F:2.9	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	Leaves	df:3,12 F:1.7	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	Fila. Algae	df:3,12 F:0.7	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Diatoms	df:2,9 F:8.6	Spring	NS	NS
		Autumn	0.006	-	-
		Winter	0.218	0.102	-
RM 30	A. Detritus	df:2,9 F:11.7	Spring	N/A	N/A
		Autumn	0.004	-	-
		Winter	0.726	0.011	-
RM 30	Leaves	df:2,9 F:2.7	Spring	N/A	N/A
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Fila. Algae	df:2,9 F:0.7	Spring	N/A	N/A
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Diatoms	df:3,12 F:26.5	Spring	N/A	N/A
		Autumn	< 0.001	-	-
		Winter	0.050	0.003	-
RM 62	A. Detritus	df:3,12 F:27.1	Spring	0.984	< 0.001
		Autumn	< 0.001	-	-
		Winter	0.856	< 0.001	-
RM 62	Leaves	df:3,12 F:3.2	Spring	0.544	< 0.001
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Leaves	df:3,12 F:3.2	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 62	Fila. Algae	df:3,12 F:1.3	Spring	NS	NS
		Autumn	NS	-	-
		Winter	NS	NS	

Site	Food Resource	Season			
RM 127	Diatoms	df:3,9 F:0.7	Summer	Autumn	Winter
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	A. Detritus	df:3,9 F:1.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	Leaves	df:3,9 F:1.1			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	Fila. Algae	df:3,9 F:1.1			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 165	Diatoms	df:3,12 F:10.0			
		Autumn	0.204	-	-
		Winter	0.850	0.055	-
		Spring	0.028	0.001	0.110
RM 165	A. Detritus	df:3,12 F:7.6			
		Autumn	0.907	-	-
		Winter	0.004	0.013	-
		Spring	0.199	0.488	0.156
RM 165	Leaves	df:3,12 F:2.0			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 165	Fila. Algae	df:3,12 F:7.9			
		Autumn	0.860	-	-
		Winter	0.004	0.017	-
		Spring	0.964	0.989	0.010
RM 225	Diatoms	df:3,12 F:8.0			
		Autumn	0.004	-	-
		Winter	0.707	0.025	-
		Spring	0.952	0.009	0.942
RM 225	A. Detritus	df:3,12 F:8.6			
		Autumn	0.028	-	-
		Winter	0.602	0.003	-
		Spring	0.824	0.006	0.977
RM 225	Leaves	df:3,12 F:20.0			
		Autumn	0.762	-	-
		Winter	< 0.001	< 0.001	-
		Spring	0.088	0.386	0.003
RM 225	Fila. Algae	df:3,12 F:1.00			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS

Appendix 9. One-way ANOVA p -values for *Gammarus lacustris* between sites by season. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0125 . NS indicates non-significant p -value. N/A indicates no data available.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Summer	Diatoms	df:4,10 F:2.4					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	NS	NS	NS	NS	N/A
Summer	A. Detritus	df:4,10 F:0.7					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	NS	NS	NS	NS	N/A
Summer	Leaves	df:4,10 F:0.1					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	NS	NS	NS	NS	N/A
Summer	Fila. Algae	df:4,10 F:0.8					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	NS	NS	NS	NS	N/A
Autumn	Diatoms	df:5,18 F:30.5					
		RM 30	0.002	-	-	-	-
		RM 62	< 0.001	< 0.001	-	-	-
		RM 127	< 0.001	0.005	0.650	-	-
		RM 165	< 0.001	0.253	0.023	0.359	-
		RM 225	< 0.001	0.002	0.871	0.998	0.188
Autumn	A. Detritus	df:5,18 F:6.5					
		RM 30	0.166	-	-	-	-
		RM 62	0.010	0.714	-	-	-
		RM 127	0.277	1.000	0.526	-	-
		RM 165	0.542	0.959	0.266	0.995	-
		RM 225	0.001	0.126	0.797	0.07	0.025
Autumn	Leaves	df:5,18 F:6.2					
		RM 30	0.009	-	-	-	-
		RM 62	0.025	0.997	-	-	-
		RM 127	0.015	1.000	1.000	-	-
		RM 165	0.001	0.877	0.636	0.780	-
		RM 225	0.273	0.513	0.781	0.637	0.093
Autumn	Fila. Algae	df:5,18 F:1.6					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Appendix 9. Continued.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Winter	Diatoms	df:5,16 F:5.1					
		RM 30	0.006	-	-	-	-
		RM 62	0.041	0.922	-	-	-
		RM 127	0.112	0.976	1.000	-	-
		RM 165	0.015	0.998	0.994	0.999	-
		RM 225	0.008	1.000	0.960	0.990	1.000
Winter	A. Detritus	df:5,16 F:2.5					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Winter	Leaves	df:5,16 F:1.2					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Winter	Fila. Algae	df:5,16 F:1.5					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Spring	Diatoms	df:5,16 F:4.0					
		RM 30	0.930	-	-	-	-
		RM 62	0.981	1.000	-	-	-
		RM 127	0.959	0.515	0.665	-	-
		RM 165	0.057	0.011	0.017	0.217	-
		RM 225	1.000	0.912	0.970	0.987	0.104
Spring	A. Detritus	df:5,16 F:1.2					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Spring	Leaves	df:5,16 F:0.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Spring	Fila. Algae						
		RM 30	N/A	N/A	-	-	-
		RM 62	N/A	N/A	-	-	-
		RM 127	N/A	N/A	N/A	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	N/A	N/A	N/A	N/A	N/A

Appendix 10. One-way ANOVA p -values for *Gammarus lacustris* between seasons by site. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0083. NS indicates non-significant p -value. N/A indicates no data available.

Site	Food Resource	Season	Summer 2006	Autumn 2006	Winter 2007
RM 0	Diatoms	df:3,13 F:0.2			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 0	A. Detritus	df:3,13 F:1.7			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 0	Leaves	df:3,13 F:1.4			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 0	Fila. Algae	df:3,13 F:10.5			
		Autumn 2006	0.002	-	-
		Winter 2007	0.030	0.519	-
		Spring 2007	1.000	0.003	0.041
RM 30	Diatoms	df:3,11 F:5.9			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 30	A. Detritus	df:3,11 F:2.6			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 30	Leaves	df:3,11 F:2.6			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 30	Fila. Algae	df:3,11 F:0.5			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 62	Diatoms	df:3,12 F:41.7			
		Autumn 2006	0.003	-	-
		Winter 2007	0.718	< 0.001	-
		Spring 2007	< 0.001	< 0.001	0.001
RM 62	A. Detritus	df:3,12 F:1.9			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 62	Leaves	df:3,12 F:0.2			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS
RM 62	Fila. Algae	df:3,12 F:1.0			
		Autumn 2006	NS	-	-
		Winter 2007	NS	NS	-
		Spring 2007	NS	NS	NS

Appendix 10. Continued.

Site	Food Resource	Season	Summer	Autumn	Winter
RM 127	Diatoms	df:3,7 F:4.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 127	A. Detritus	df:3,7 F:1.3			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 127	Leaves	df:3,7 F:7.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 127	Fila. Algae	df:3,7 F:63.2			
		Autumn	0.466	-	-
		Winter	< 0.001	< 0.001	-
RM 165	Diatoms	df:2,8 F:2.6			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
RM 165	A. Detritus	df:2,8 F:0.3			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
RM 165	Leaves	df:2,8 F:7.2			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
RM 165	Fila. Algae	df:2,8 F:1.6			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
RM 225	Diatoms	df:3,9 F:13.4			
		Autumn	0.037	-	-
		Winter	0.729	0.081	-
RM 225	A. Detritus	df:3,9 F:9.4			
		Autumn	0.422	-	-
		Winter	0.752	0.045	-
RM 225	Leaves	df:3,9 F:1.1			
		Autumn	0.078	0.003	0.184
		Winter	NS	NS	-
RM 225	Fila. Algae	df:3,9 F:3.2			
		Autumn	NS	NS	NS
		Winter	NS	NS	-
RM 225		Spring	NS	NS	NS

Appendix 11. One-way ANOVA p -values for NZMS between sites by season. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0125 . NS indicates non-significant p -value. N/A indicates no data available.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Summer	Diatoms	df:4,11 F:2.4					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	NS	NS	NS	NS	N/A
Summer	A. Detritus	df:4,11 F:2.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	NS	NS	NS	NS	N/A
Summer	Leaves	df:4,11 F:7.2					
		RM 30	0.022	-	-	-	-
		RM 62	0.700	0.818	-	-	-
		RM 127	0.005	0.778	0.422	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	0.855	0.110	0.959	0.024	N/A
Summer	Fila. Algae	df:4,11 F:0.6					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	N/A	N/A	N/A	N/A	-
		RM 225	NS	NS	NS	NS	N/A
Autumn	Diatoms	df:5,18 F:17.3					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.777	-	-	-
		RM 127	< 0.001	1.000	0.758	-	-
		RM 165	< 0.001	0.992	0.442	0.994	-
		RM 225	< 0.001	0.350	0.972	0.333	0.139
Autumn	A. Detritus	df:5,18 F:21.3					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.988	-	-	-
		RM 127	< 0.001	1.000	0.991	-	-
		RM 165	0.001	0.554	0.240	0.536	-
		RM 225	< 0.001	0.133	0.361	0.141	0.004
Autumn	Leaves	df:5,18 F:5.1					
		RM 30	0.041	-	-	-	-
		RM 62	0.003	0.825	-	-	-
		RM 127	0.106	0.996	0.549	-	-
		RM 165	0.012	0.991	0.987	0.887	-
		RM 225	0.423	0.752	0.157	0.950	0.413
Autumn	Fila. Algae	df:5,18 F:1.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Appendix 11. Continued.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Winter	Diatoms	df:4,11 F:11.9					
		RM 30	0.014	-	-	-	-
		RM 62	N/A	N/A	-	-	-
		RM 127	0.001	0.086	N/A	-	-
		RM 165	0.002	0.661	N/A	0.428	-
		RM 225	0.044	1.000	N/A	0.169	0.821
Winter	A. Detritus	df:4,11 F:6.3					
		RM 30	0.162	-	-	-	-
		RM 62	N/A	N/A	-	-	-
		RM 127	0.007	0.193	N/A	-	-
		RM 165	0.019	0.677	N/A	0.706	-
		RM 225	0.717	0.933	N/A	0.113	0.389
Winter	Leaves	df:4,11 F:21.8					
		RM 30	< 0.001	-	-	-	-
		RM 62	N/A	N/A	-	-	-
		RM 127	0.001	0.987	N/A	-	-
		RM 165	< 0.001	0.999	N/A	0.999	-
		RM 225	< 0.001	0.613	N/A	0.485	0.489
Winter	Fila. Algae	df:4,11 F:5.5					
		RM 30	NS	-	-	-	-
		RM 62	N/A	N/A	-	-	-
		RM 127	NS	NS	N/A	-	-
		RM 165	NS	NS	N/A	NS	-
		RM 225	NS	NS	N/A	NS	NS
Spring	Diatoms	df:5,18 F:10.7					
		RM 30	0.001	-	-	-	-
		RM 62	< 0.001	0.933	-	-	-
		RM 127	0.003	0.999	0.801	-	-
		RM 165	< 0.001	0.873	1.000	0.706	-
		RM 225	< 0.001	0.861	1.000	0.690	1.000
Spring	A. Detritus	df:5,18 F:5.5					
		RM 30	0.008	-	-	-	-
		RM 62	0.003	0.993	-	-	-
		RM 127	0.025	0.994	0.882	-	-
		RM 165	0.008	1.000	0.994	0.993	-
		RM 225	0.016	1.000	0.951	1.000	0.999
Spring	Leaves	df:5,18 F:1.4					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Spring	Fila. Algae	df:5,18 F:1.0					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS

Appendix 12. One-way ANOVA p -values for NZMS between seasons by site. Numbers in bold reflect values with a bonferonni corrected p -value < 0.0083. NS indicates non-significant p -value. N/A indicates no data available.

Site	Food Resource	Season	Summer	Autumn	Winter
RM 0	Diatoms	df:3,12 F:0.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	A. Detritus	df:3,12 F:0.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 0	Leaves	df:3,12 F:12.2			
		Autumn	NS	NS	NS
		Spring	NS	NS	NS
RM 0	Fila. Algae	df:3,12 F:0.7			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	Diatoms	df:3,12 F:1.1			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 30	A. Detritus	df:3,12 F:10.9			
		Autumn	NS	NS	NS
		Spring	NS	NS	NS
RM 30	Leaves	df:3,12 F:7.7			
		Autumn	0.015	-	-
		Winter	0.964	0.007	-
RM 30	Fila. Algae	df:3,12 F:0.1			
		Autumn	0.009	0.989	0.004
		Spring	0.196	-	-
RM 62	Diatoms	df:2,6 F:0.1			
		Autumn	0.461	0.015	-
		Winter	0.072	0.925	0.005
RM 62	A. Detritus	df:2,6 F:0.5			
		Autumn	N/A	-	-
		Winter	N/A	N/A	-
RM 62	Leaves	df:2,6 F:3.1			
		Autumn	N/A	N/A	N/A
		Spring	NS	NS	N/A
RM 62	Fila. Algae	df:2,6 F:0.5			
		Autumn	NS	-	-
		Winter	N/A	N/A	-
RM 62	Fila. Algae	df:2,6 F:0.5			
		Autumn	NS	NS	N/A
		Spring	NS	NS	N/A

Site	Food Resource	Season			
RM 127	Diatoms	df:3,9 F:6.2	Summer	Autumn	Winter
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	A. Detritus	df:3,9 F:11.8			
		Autumn	0.002	-	-
		Winter	0.005	0.994	-
		Spring	0.007	0.807	0.759
RM 127	Leaves	df:3,9 F:6.3			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 127	Fila. Algae				
		Autumn	N/A	-	-
		Winter	N/A	N/A	-
		Spring	N/A	N/A	N/A
RM 165	Diatoms	df:2,9 F:1.3			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
		Spring	N/A	NS	NS
RM 165	A. Detritus	df:2,9 F:1.7			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
		Spring	N/A	NS	NS
RM 165	Leaves	df:2,9 F:3.8			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
		Spring	N/A	NS	NS
RM 165	Fila. Algae	df:2,9 F:2.5			
		Autumn	N/A	-	-
		Winter	N/A	NS	-
		Spring	N/A	NS	NS
RM 225	Diatoms	df:3,10 F:7.0			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 225	A. Detritus	df:3,10 F:5.0			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 225	Leaves	df:3,10 F:4.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 225	Fila. Algae	df:3,10 F:0.7			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS

Appendix 13. One-way ANOVA p -values for chironomids between sites by season. Numbers in bold reflect values with a bonferroni corrected p -value < 0.0125 . NS indicates non-significant p -value. N/A indicates no data available.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Summer	Diatoms	df:5,18 F:6.0					
		RM 30	0.713	-	-	-	-
		RM 62	0.085	0.679	-	-	-
		RM 127	0.001	0.019	0.301	-	-
		RM 165	0.345	0.986	0.956	0.071	-
		RM 225	0.038	0.439	0.998	0.516	0.810
Summer	A. Detritus	df:5,18 F:1.7					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Summer	Leaves	df:5,18 F:3.2					
		RM 30	0.999	-	-	-	-
		RM 62	0.682	0.854	-	-	-
		RM 127	0.025	0.048	0.353	-	-
		RM 165	0.863	0.963	0.999	0.207	-
		RM 225	0.324	0.498	0.987	0.717	0.917
Summer	Fila. Algae	df:5,18 F:1.0					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Autumn	Diatoms	df:5,12 F:7.6					
		RM 30	0.955	-	-	-	-
		RM 62	0.140	0.260	-	-	-
		RM 127	0.025	0.034	0.987	-	-
		RM 165	0.004	0.005	0.357	0.510	-
		RM 225	0.057	0.092	1.000	0.989	0.274
Autumn	A. Detritus	df:5,12 F:3.5					
		RM 30	0.955	-	-	-	-
		RM 62	0.140	0.260	-	-	-
		RM 127	0.025	0.034	0.987	-	-
		RM 165	0.004	0.005	0.357	0.510	-
		RM 225	0.057	0.092	1.000	0.989	0.274
Autumn	Leaves	df:5,12 F:1.3					
		RM 30	NS	-	-	-	-
		RM 62	NS	NS	-	-	-
		RM 127	NS	NS	NS	-	-
		RM 165	NS	NS	NS	NS	-
		RM 225	NS	NS	NS	NS	NS
Autumn	Fila. Algae	df:5,12 F:1123					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	1.000	-	-	-
		RM 127	< 0.001	1.000	1.000	-	-
		RM 165	< 0.001	1.000	1.000	1.000	-
		RM 225	< 0.001	1.000	1.000	1.000	1.000

Appendix 13. Continued.

Season	Food Resource	Site	RM 0	RM 30	RM 62	RM 127	RM 165
Winter	Diatoms	df:5,18 F:26.5					
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.910	-	-	-
		RM 127	< 0.001	1.000	0.852	-	-
		RM 165	< 0.001	0.390	0.920	0.316	-
Winter	A. Detritus	df:5,18 F:34.3					
		RM 225	< 0.001	0.155	0.627	0.119	0.990
		RM 30	< 0.001	-	-	-	-
		RM 62	< 0.001	0.781	-	-	-
		RM 127	< 0.001	0.864	1.000	-	-
Winter	Leaves	df:5,18 F:8.5					
		RM 165	< 0.001	0.155	0.796	0.700	-
		RM 225	< 0.001	0.001	0.019	0.013	0.216
		RM 30	0.207	-	-	-	-
		RM 62	0.039	0.942	-	-	-
Winter	Fila. Algae	df:5,18 F:0.7					
		RM 127	0.001	0.095	0.409	-	-
		RM 165	0.010	0.640	0.985	0.783	-
		RM 225	< 0.001	0.043	0.222	0.998	0.542
		RM 30	NS	-	-	-	-
Spring	Diatoms	df:4,15 F:7.3					
		RM 30	N/A	-	-	-	-
		RM 62	0.036	N/A	-	-	-
		RM 127	0.113	N/A	0.995	-	-
		RM 165	0.107	N/A	0.974	1.000	-
Spring	A. Detritus	df:4,15 F:8.0					
		RM 225	0.001	N/A	0.340	0.237	0.128
		RM 30	N/A	-	-	-	-
		RM 62	0.014	N/A	-	-	-
		RM 127	0.081	N/A	0.963	-	-
Spring	Leaves	df:4,15 F:6.0					
		RM 165	0.034	N/A	0.989	0.999	-
		RM 225	< 0.001	N/A	0.511	0.244	0.268
		RM 30	N/A	-	-	-	-
		RM 62	0.095	N/A	-	-	-
Spring	Fila. Algae	df:4,15 F:1.4					
		RM 127	0.128	N/A	1.000	-	-
		RM 165	0.166	N/A	0.997	0.997	-
		RM 225	0.002	N/A	0.300	0.394	0.178
		RM 30	N/A	-	-	-	-
		df:4,15 F:1.4					
		RM 62	NS	N/A	-	-	-
		RM 127	NS	N/A	NS	-	-
		RM 165	NS	N/A	NS	NS	-
		RM 225	NS	N/A	NS	NS	NS

Site	Food Resource	Season			
RM 0	Diatoms	df:3,10 F:19.9	Summer	Autumn	Winter
		Autumn	0.114	-	-
		Winter	0.004	< 0.001	-
		Spring	0.007	0.001	0.965
RM 0	A. Detritus	df:3,10 F:13.4			
		Autumn	0.877	-	-
		Winter	0.002	0.026	-
		Spring	0.002	0.028	1.000
RM 0	Leaves	df:3,10 F:5.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 0	Fila. Algae	df:3,10 F:13.2			
		Autumn	0.001	-	-
		Winter	0.825	0.002	-
		Spring	0.534	0.003	0.950
RM 30	Diatoms	df:2,9 F:4.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	N/A	N/A	N/A
RM 30	A. Detritus	df:2,9 F:5.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	N/A	N/A	N/A
RM 30	Leaves	df:2,9 F:0.7			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	N/A	N/A	N/A
RM 30	Fila. Algae	df:2,9 F:0.7			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	N/A	N/A	N/A
RM 62	Diatoms	df:3,10 F:1.1			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 62	A. Detritus	df:3,10 F:0.5			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 62	Leaves	df:3,10 F:3.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS
RM 62	Fila. Algae	df:3,10 F:0.7			
		Autumn	NS	-	-
		Winter	NS	NS	-
		Spring	NS	NS	NS

Appendix 14. Continued.

Site	Food Resource	Season	Summer	Autumn	Winter
RM 127	Diatoms	df:3,11 F:5.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 127	A. Detritus	df:3,11 F:1.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 127	Leaves	df:3,11 F:6.3			
		Autumn	0.146	-	-
		Winter	0.100	0.995	-
RM 127	Fila. Algae	df:3,11 F:1.2			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 165	Diatoms	df:3,10 F:5.4			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 165	A. Detritus	df:3,10 F:0.8			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 165	Leaves	df:3,10 F:2.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 165	Fila. Algae	df:3,10 F:2.6			
		Autumn	NS	NS	NS
		Spring	NS	NS	NS
RM 225	Diatoms	df:3,13 F:1.8			
		Autumn	N/A	-	-
		Winter	N/A	N/A	-
RM 225	A. Detritus	df:3,13 F:2.4			
		Autumn	N/A	N/A	N/A
		Spring	N/A	N/A	N/A
RM 225	Leaves	df:3,13 F:0.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 225	Fila. Algae	df:3,13 F:0.6			
		Autumn	NS	NS	NS
		Spring	NS	NS	NS
RM 225	Fila. Algae	df:3,13 F:0.6			
		Autumn	NS	-	-
		Winter	NS	NS	-
RM 225	Fila. Algae	df:3,13 F:0.6			
		Autumn	NS	NS	NS
		Spring	NS	NS	NS

APPENDIX B

ALGAL COMMUNITY COMPOSITION TABLES

Appendix 15. Algal species and corresponding species codes (abbreviations).	
Species Name	Species Code
<i>Achnanthes microcephala</i> (Kützing) Grunow/ <i>Achnanthes minutissima</i> Kützing	ACHMIC
<i>Amphora perpusilla</i> (Grunow) Grunow	AMPPER
<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	COCEUG
<i>Cocconeis pediculus</i> Ehrenberg	COCPED
<i>Cyclotella comta</i> (Ehrenberg) Kützing	CYCCOM
<i>Cymbella affinis</i> Kützing	CYMAFF
<i>Cymbella lunata</i> W. Smith	CYMLUN
<i>Cymbella mexicana</i> (Ehr.) Cleve	CYMMEX
<i>Encyonema auerswaldii</i> Rabenhorst	CYMPRA
<i>Encyonema prostratum</i> (Berkeley) Kützing	CYMPRO
<i>Diatoma moniliformis</i> Kützing	DIAMON
<i>Diatoma</i> sp. 1	DIASP1
<i>Diatoma vulgare</i> Bory	DIAVUL
<i>Ellerbeckia arenaria</i> (Moore) R.M. Crawford	ELLER
<i>Fragilaria crotonensis</i> Kitton	FRACRO
<i>Fragilaria</i> sp. 2	FRASP2
<i>Fragilaria</i> sp. 4	FRASP4
<i>Gomphonema olivaceum</i> var. <i>calcareum</i> (Cl.) Cleve	GOMOLC
<i>Gomphonema olivaceum</i> (Hornemann) Brébisson	GOMOLI
<i>Gomphonema clavatum</i> Ehrenberg	GOMSUB
Green algae zoospores	GRNALG
<i>Gyrosigma spencerii</i> et varieties	GYRCUR
<i>Melosira varians</i> C. Agardh	MELVAR
<i>Navicula cryptotenella</i> Lange-Bertalot	NAVCRY
<i>Navicula tripunctata</i> (O.F. Müller) Bory	NAVTRI
<i>Nitzschia denticula</i> Grunow/ <i>Denticula elegans</i> Kützing	NITDEN
<i>Nitzschia dissipata</i> (Kützing) Grunow	NITDIS
<i>Nitzschia fonticola</i> (Grunow) Grunow	NITFON
<i>Nitzschia kutzingiana</i> Hilse	NITKUT
<i>Nitzschia palea</i> (Kützing) W. Smith	NITPAL
<i>Martyana martyi</i> (Héribaud) F.E. Round	OPEMAR
<i>Pinnularia</i> sp. 1	PINSP1
<i>Reimeria sinuata</i> (Gregory) Kociolek & Stoermer	REISIN
<i>Rhoicosphenia curvata</i> (Kützing) Grunow	RHOCUR
<i>Synedra fasciculata</i> (Agardh) Kützing	SYNAFF
<i>Synedra</i> sp. 1	SYNGIS1
<i>Synedra ulna</i> (Nitzsch) Ehrenberg	SYNULN

Appendix 16. Mean percent abundances (SE) of algal taxa in sestonic algal assemblages at each site during January 2007.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Achnanthes lanceolata</i> var. <i>omissa</i> Reimer	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Achnanthes microcephala</i> (Kützing) Grunow/ <i>Achnanthes minutissima</i> Kützing	9.4 (0.5)	18.0 (0.5)	15.9 (3.1)	15.6 (1.5)	14.7 (4.7)	13.0 (1.0)
<i>Achnanthes sublaevis</i> var. <i>crassa</i> C.W. Reimer	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)
<i>Achnanthes wellsiae</i> Reimer	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Achnanthidium affine</i> (Grunow) Czarnecki	0.0 (0.0)	0.4 (0.4)	0.0 (0.0)	0.2 (0.2)	0.3 (0.3)	0.0 (0.0)
<i>Amphipleura</i> sp. 1	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Amphora montana</i> Krasske	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.3 (0.2)	0.0 (0.0)
<i>Amphora ovalis</i> (Kützing) Kützing	0.0 (0.0)	0.4 (0.2)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)
<i>Amphora pediculus</i> (Kützing) Grunow ex A. Schmidt	0.1 (0.1)	0.5 (0.2)	0.7 (0.1)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)
<i>Amphora perpusilla</i> (Grunow) Grunow	1.3 (0.5)	3.1 (0.4)	2.8 (0.1)	7.1 (3.4)	1.1 (0.6)	3.1 (0.8)
<i>Brachysira vitrea</i> (Grunow) R. Ross	0.2 (0.2)	0.3 (0.3)	0.4 (0.2)	2.6 (2.3)	0.2 (0.2)	0.0 (0.0)
<i>Cladophora glomerata</i> (Linnaeus) Kützing	0.2 (0.2)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Cocconeis neodiminuta</i> Krammer	0.3 (0.2)	0.0 (0.0)	0.0 (0.0)	0.6 (0.4)	0.0 (0.0)	0.0 (0.0)
<i>Cocconeis pediculus</i> Ehrenberg	9.2 (3.0)	6.6 (1.8)	5.3 (0.7)	4.5 (1.5)	3.9 (0.8)	5.4 (1.8)
<i>Cocconeis placentula</i> Ehrenberg	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	2.7 (0.9)	1.8 (0.7)	0.9 (0.2)	1.1 (0.2)	1.5 (0.2)	1.5 (0.6)
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehrenberg) van Heurck	0.8 (0.1)	1.2 (0.3)	1.4 (0.4)	0.7 (0.5)	0.6 (0.3)	1.0 (0.5)
<i>Craticula accomoda</i> (Hustedt) D.G. Mann	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cyclotella comta</i> (Ehrenberg) Kützing	0.8 (0.2)	1.0 (0.1)	2.7 (1.1)	0.8 (0.6)	0.5 (0.3)	1.3 (0.4)
<i>Cyclotella meneghiniana</i> Kützing	0.8 (0.4)	0.5 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cyclotella</i> sp. 2	0.0 (0.0)	0.3 (0.3)	0.6 (0.6)	0.7 (0.7)	1.6 (0.9)	2.1 (0.1)
<i>Cyclotella</i> sp. 3	0.8 (0.4)	0.1 (0.1)	0.7 (0.7)	0.9 (0.5)	0.6 (0.3)	0.2 (0.2)
<i>Cymbella affinis</i> Kützing	1.4 (0.9)	0.2 (0.2)	0.9 (0.5)	0.5 (0.3)	0.0 (0.0)	0.3 (0.3)
<i>Cymbella amphicephala</i> Näegeli	0.2 (0.1)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	1.3 (1.1)	0.0 (0.0)
<i>Cymbella cymbiformis</i> var. <i>nonpunctata</i> Fontell	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella laevis</i> Näegeli	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella lunata</i> W. Smith	0.2 (0.2)	0.4 (0.4)	0.0 (0.0)	0.3 (0.3)	0.1 (0.1)	10.3 (10.3)

Appendix 16. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Cymbella mexicana</i> (Ehrenberg)						
Cleve	1.0 (1.0)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Cymbella microcephala</i> var.						
<i>crassa</i> Reimer	0.4 (0.1)	0.4 (0.2)	1.4 (0.7)	0.4 (0.2)	0.9 (0.7)	0.5 (0.1)
<i>Cymbella pusilla</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Cymbella</i> sp. 1	0.6 (0.2)	1.3 (0.1)	0.2 (0.2)	0.0 (0.0)	0.4 (0.3)	0.2 (0.2)
<i>Diatoma hiemale</i> var. <i>mesodon</i>						
(Ehrenberg) Grunow	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Diatoma moniliformis</i> Kützing	3.8 (0.8)	5.8 (0.6)	4.0 (0.2)	5.3 (1.2)	5.9 (0.6)	5.3 (2.0)
<i>Diatoma</i> sp. 1	1.9 (0.3)	2.1 (1.3)	2.2 (1.4)	2.6 (0.3)	1.9 (1.0)	3.9 (0.8)
<i>Diatoma</i> sp. 2	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma tenue</i> var. <i>elongatum</i>						
Lyngbye	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma vulgare</i> Bory	4.6 (1.5)	2.0 (1.1)	2.0 (1.5)	1.4 (0.6)	1.3 (0.3)	1.0 (0.1)
<i>Diploneis oculata</i> (Brébisson)						
Cleve	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Ellerbeckia arenaria</i> (Moore)						
R.M. Crawford	3.9 (3.8)	1.3 (0.6)	0.2 (0.2)	1.1 (0.3)	0.3 (0.2)	1.6 (1.3)
<i>Encyonema auerswaldii</i>						
Rabenhorst	0.1 (0.1)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.1 (0.1)
<i>Encyonema minutum</i> (Hilse in						
Rabenhorst) D.G. Mann	0.6 (0.6)	0.2 (0.1)	0.7 (0.3)	1.4 (0.4)	0.5 (0.3)	1.1 (0.2)
<i>Encyonema prostratum</i>						
(Berkeley) Kützing	0.2 (0.1)	0.4 (0.2)	0.7 (0.5)	0.0 (0.0)	0.0 (0.0)	0.5 (0.3)
<i>Encyonopsis</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)
Filamentous algae sp. 2	0.0 (0.0)	0.5 (0.5)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria crotonensis</i> Kitton	34.7 (8.9)	10.2 (1.6)	0.9 (0.9)	9.8 (3.4)	8.7 (5.5)	2.1 (1.1)
<i>Fragilaria</i> sp. 2	0.3 (0.3)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria</i> sp. 4	1.2 (0.6)	1.2 (0.4)	4.0 (2.1)	1.5 (0.3)	5.4 (3.3)	1.8 (0.1)
<i>Frustulia vulgaris</i> (Thwaites) De						
Toni	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)
<i>Geissleria</i> sp. 1	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Gomphonema clavatum</i> Ehrenberg	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)
<i>Gomphonema truncatum</i>						
Ehrenberg	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Gomphonema herculeanum</i>						
Ehrenberg	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)
<i>Gomphonema olivaceum</i>						
(Hornemann) Brébisson	2.4 (0.2)	1.6 (0.8)	2.3 (0.8)	2.6 (0.3)	2.0 (0.7)	1.9 (0.5)
<i>Gomphonema olivaceum</i> var.						
<i>calcareum</i> Cleve	0.0 (0.0)	0.4 (0.2)	0.2 (0.2)	0.6 (0.1)	0.3 (0.3)	0.6 (0.3)
<i>Gomphonema parvulum</i>						
(Kützing) Kützing	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Gomphonema</i> sp. 2	0.5 (0.3)	0.1 (0.1)	0.6 (0.6)	0.2 (0.2)	0.5 (0.3)	0.0 (0.0)

Appendix 16. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Gomphonema</i> sp. 3	0.1 (0.1)	0.4 (0.4)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)	0.1 (0.1)
<i>Gomphonema</i> sp. 4	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)
Green algae zoospores	3.2 (2.3)	13.8 (5.9)	30.9 (7.3)	16.1 (2.4)	28.4 (2.3)	20.5 (5.5)
<i>Gyrosigma eximium</i> (Thwaites) Van Heurck	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)
<i>Gyrosigma spencerii</i> et varieties	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Hantzschia amphioxys</i> var. <i>capitata</i> O.F. Müller	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.1 (1.1)	0.0 (0.0)
<i>Karayevia clevei</i> (Grunow in Cleve & Grunow) Round & Bukhtiyarova	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Martyana martyi</i> (Héribaud) F.E. Round	0.3 (0.3)	0.1 (0.1)	0.3 (0.3)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)
<i>Melosira varians</i> C. Agardh	0.1 (0.1)	0.1 (0.1)	0.6 (0.6)	0.0 (0.0)	0.5 (0.5)	1.1 (0.8)
<i>Navicula cryptocephala</i> var. <i>veneta</i> (Kützing) Rabenhorst	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)
<i>Navicula confervacea</i> (Kützing) Grunow	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Navicula cryptocephala</i> Kützing	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.3 (0.3)	0.1 (0.1)	0.1 (0.1)
<i>Navicula cryptonella</i> Lange- Bertalot	0.1 (0.1)	0.5 (0.2)	0.6 (0.6)	3.1 (0.8)	0.9 (0.2)	0.6 (0.3)
<i>Navicula gregaria</i> Donkin	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Navicula laterostrata</i> Hustedt	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Navicula subtilissima</i> Cleve	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Navicula tripunctata</i> (O.F. Müller) Bory	0.5 (0.2)	0.3 (0.2)	1.0 (0.5)	0.7 (0.4)	0.4 (0.3)	0.3 (0.1)
<i>Navicula veneta</i> Kützing	0.0 (0.0)	0.4 (0.2)	0.9 (0.2)	0.6 (0.1)	0.1 (0.1)	0.0 (0.0)
<i>Nitzschia acicularis</i> (Kützing) W. Smith var. <i>closterioides</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)
<i>Nitzschia amphibia</i> Grunow	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)
<i>Nitzschia amphibia</i> sp. 1	0.1 (0.1)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia apiculata</i> (W. Gregory) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)

Appendix 16. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Nitzschia capitellata</i> Hustedt	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia denticula</i> Grunow/ <i>Denticula elegans</i> Kützing	0.9 (0.5)	1.7 (0.5)	0.9 (0.5)	0.2 (0.2)	0.9 (0.4)	0.5 (0.2)
<i>Nitzschia dissipata</i> (Kützing) Grunow	0.2 (0.1)	0.2 (0.1)	0.9 (0.5)	1.7 (1.0)	1.0 (0.3)	6.4 (1.0)
<i>Nitzschia kutzingiana</i> Hilse	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)
<i>Nitzschia linearis</i> (Agardh) W. Smith	0.0 (0.0)	0.4 (0.3)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)
<i>Nitzschia microcephala</i> Grunow	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia palea</i> (Kützing) W. Smith	0.1 (0.1)	0.9 (0.3)	1.1 (0.3)	0.7 (0.2)	1.3 (0.3)	2.1 (0.3)
<i>Nitzschia</i> sp. 2	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Nitzschia</i> sp. 9	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)
<i>Nitzschia tubicola</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Pinnularia</i> sp. 1	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Planothidium frequentissimum</i> (Lange-Bertalot) Round & L. Bukhtiyarova	0.3 (0.2)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.4 (0.2)	0.3 (0.2)
<i>Planothidium lanceolatum</i> (Brébisson ex Kützing) Lange- Bertalot	0.0 (0.0)	0.3 (0.2)	0.0 (0.0)	0.3 (0.3)	0.3 (0.2)	0.5 (0.3)
<i>Pleurosira laevis</i> (Ehrenberg)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Reimeria sinuata</i> (Gregory) Kociolek & Stoermer	0.3 (0.2)	0.1 (0.1)	0.2 (0.2)	0.9 (0.9)	0.3 (0.3)	0.2 (0.2)
<i>Rhoicosphenia curvata</i> (Kützing) Grunow	4.8 (1.3)	8.7 (0.6)	6.3 (1.0)	8.5 (0.6)	3.8 (1.1)	3.5 (0.6)
<i>Staurosira venter</i> (Ehrenberg) H. Kobayasi	0.5 (0.2)	0.5 (0.5)	0.0 (0.0)	0.2 (0.2)	0.2 (0.2)	0.1 (0.1)
<i>Staurosirella leptostauron</i> (Ehrenberg) D.M. Williams & Round	0.2 (0.2)	0.1 (0.1)	1.2 (0.9)	0.0 (0.0)	0.8 (0.4)	0.6 (0.3)
<i>Surirella brightwellii</i> W. Smith	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)
<i>Surirella ovalis</i> Brébisson	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.5 (0.1)
<i>Synedra acus</i> Kützing	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Synedra affinis</i> Kützing	0.3 (0.3)	0.2 (0.2)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Synedra amphicephala</i> var. <i>austriaca</i> (Grunow) Hustedt	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.6 (0.4)
<i>Synedra fasciculata</i> (Agardh) Kützing	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)
<i>Synedra mazamaensis</i> Sovereign	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Synedra</i> sp. 1	0.4 (0.2)	1.7 (0.4)	0.5 (0.3)	0.3 (0.3)	0.3 (0.3)	0.0 (0.0)
<i>Synedra ulna</i> (Nitzsch) Ehrenberg	1.3 (0.5)	3.9 (0.4)	1.7 (0.3)	1.4 (0.9)	1.2 (0.5)	1.5 (0.1)

Appendix 17. Mean percent abundances (SE) of algal taxa in epilithic algal assemblages at each site during January 2007.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Achnanthes lanceolata</i> var. <i>omissa</i> Reimer	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Achnanthes microcephala</i> (Kützing) Grunow/ <i>Achnanthes minutissima</i> Kützing	42.3 (6.3)	5.6 (2.6)	2.3 (0.6)	27.6 (7.0)	21.6 (19.4)	16.5 (5.3)
<i>Amphora pediculus</i> (Kützing) Grunow ex A. Schmidt	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Amphora perpusilla</i> (Grunow) Grunow	3.3 (0.6)	33.8 (15.8)	72.6 (13.4)	3.6 (1.6)	25.3 (15.0)	3.8 (3.8)
<i>Anabaena</i> sp. 1	0.1 (0.1)	0.3 (0.3)	0.7 (0.3)	1.5 (0.8)	2.1 (1.5)	2.1 (1.3)
<i>Anabaena</i> sp. 2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Caloneis bacillum</i> (Grunow) Cleve	0.0 (0.0)	0.0 (0.0)	0.3 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cladophora fracta</i> (O.F. Müller ex Vahl) Kützing	0.1 (0.1)	0.8 (0.8)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cladophora glomerata</i> (Linnaeus) Kützing	0.3 (0.2)	0.0 (0.0)	0.1 (0.1)	0.3 (0.3)	0.0 (0.0)	2.8 (2.8)
<i>Cocconeis neodiminuta</i> Krammer	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cocconeis pediculus</i> Ehrenberg	1.6 (0.4)	1.1 (0.5)	0.5 (0.3)	1.3 (0.3)	0.7 (0.7)	6.0 (6.0)
<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	0.7 (0.2)	2.9 (0.6)	0.5 (0.1)	0.2 (0.1)	0.3 (0.2)	9.5 (7.2)
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehrenberg) van Heurck	0.3 (0.1)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.0 (0.0)	0.0 (0.0)
<i>Coscinodiscus</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Cyclotella comta</i> (Ehrenberg) Kützing	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cyclotella meneghiniana</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.1)
<i>Cyclotella ocellata</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)
<i>Cymbella affinis</i> Kützing	0.4 (0.2)	0.0 (0.0)	2.8 (2.3)	2.0 (0.7)	0.1 (0.1)	1.6 (0.5)
<i>Cymbella amphicephala</i> Näegeli	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella mexicana</i> (Ehrenberg) Cleve	0.4 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella mexicana</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.0 (0.0)
<i>Cymbella microcephala</i> var. <i>crassa</i> Reimer	0.7 (0.2)	0.0 (0.0)	0.2 (0.2)	1.0 (0.6)	0.1 (0.1)	0.0 (0.0)
<i>Cymbella proxima</i> R.M. Patrick &	0.0 (0.0)	0.4 (0.4)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella</i> sp. 1	1.2 (0.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma hiemale</i> var. <i>mesodon</i> (Ehrenberg) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma moniliformis</i> Kützing	3.5 (3.0)	0.1 (0.1)	0.2 (0.2)	3.2 (1.0)	0.2 (0.2)	4.8 (3.1)
<i>Diatoma</i> sp. 1	0.9 (0.7)	0.3 (0.3)	0.1 (0.1)	1.6 (0.8)	0.2 (0.2)	0.2 (0.2)
<i>Diatoma</i> sp. 2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.1 (0.1)	0.0 (0.0)

Appendix 17. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Diatoma tenue</i> var. <i>elongatum</i>						
Lyngbye	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma vulgare</i> Bory	4.2 (2.4)	0.0 (0.0)	0.3 (0.2)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma vulgare</i> var. <i>linearis</i>						
Grunow	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	1.2 (1.2)	0.0 (0.0)	0.0 (0.0)
<i>Ellerbeckia arenaria</i> (Moore)						
R.M. Crawford	2.1 (1.9)	13.1 (2.2)	0.8 (0.4)	0.5 (0.2)	10.6 (5.6)	3.6 (3.2)
<i>Encyonema auerswaldii</i>						
Rabenhorst	0.1 (0.1)	0.0 (0.0)	0.5 (0.4)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Encyonema minutum</i> (Hilse in						
Rabenhorst) D.G. Mann	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Encyonema prostratum</i>						
(Berkeley) Kützing	0.3 (0.1)	18.4 (7.3)	1.7 (0.5)	0.1 (0.1)	3.4 (2.2)	11.8 (11.8)
<i>Fragilaria capucina</i> var.						
<i>vaucheriae</i> (Kützing) Lange-						
Bertalot	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.6 (0.6)
<i>Fragilaria crotonensis</i> Kitton	0.4 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria</i> sp. 1	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria</i> sp. 2	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria</i> sp. 4	7.7 (5.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Gomphonema clavatum</i> Ehrenberg	3.3 (2.2)	0.0 (0.0)	0.8 (0.8)	1.8 (0.9)	0.3 (0.3)	0.0 (0.0)
<i>Gomphonema intracatum</i>						
Kützing	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.2 (0.2)
<i>Gomphonema olivaceum</i>						
(Hornemann) Brébisson	3.6 (1.8)	0.0 (0.0)	2.5 (2.1)	5.2 (0.9)	0.9 (0.9)	0.0 (0.0)
<i>Gomphonema olivaceum</i> var.						
<i>calcareum</i> Cleve	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	4.6 (4.6)	0.1 (0.1)	0.0 (0.0)
<i>Gomphonema parvulum</i>						
(Kützing) Kützing	0.0 (0.0)	0.0 (0.0)	0.5 (0.5)	0.3 (0.3)	0.2 (0.2)	0.0 (0.0)
<i>Gomphonema</i> sp. 2	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.7 (0.3)	0.3 (0.3)	0.6 (0.6)
<i>Gomphonema</i> sp. 8	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (0.9)	0.2 (0.2)	0.0 (0.0)
<i>Gomphonema truncatum</i>						
Ehrenberg	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.2 (0.2)	0.0 (0.0)
Green algae zoospores	0.0 (0.0)	0.2 (0.2)	1.6 (0.5)	0.0 (0.0)	3.6 (3.2)	13.5 (13.5)
<i>Gyrosigma attenuata</i> sp. 1	0.0 (0.0)	0.5 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Gyrosigma eximium</i> (Thwaites)						
Van Heurck	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Gyrosigma spencerii</i> et varieties	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	2.2 (1.4)	0.0 (0.0)
<i>Karayevia clevei</i> (Grunow in						
Cleve & Grunow) Round &						
Bukhtiyarova	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Martyana martyi</i> (Héribaud) F.E.						
Round	0.4 (0.1)	0.0 (0.0)	0.0 (0.0)	0.5 (0.4)	0.0 (0.0)	0.0 (0.0)
<i>Melosira varians</i> C. Agardh	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)
<i>Navicula cryptocephala</i> Kützing	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Navicula cryptonella</i> Lange-						
Bertalot	0.8 (0.6)	0.2 (0.2)	2.5 (0.9)	7.6 (3.6)	0.3 (0.3)	0.6 (0.6)

Appendix 17. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Navicula mutica</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Navicula radiosa</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Navicula</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)
<i>Navicula</i> sp. 2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Navicula tripunctata</i> (O.F. Müller) Bory	0.0 (0.0)	0.6 (0.1)	1.2 (0.4)	2.5 (1.2)	1.5 (1.2)	0.0 (0.0)
<i>Navicula veneta</i> Kützing	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	2.1 (1.1)	0.1 (0.1)	0.0 (0.0)
<i>Navicula viridula</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia brevissima</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.0 (0.0)
<i>Nitzschia capitellata</i> Hustedt	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Nitzschia denticula</i> Grunow/ <i>Denticula elegans</i> Kützing	4.5 (2.3)	0.0 (0.0)	0.2 (0.2)	0.4 (0.3)	0.0 (0.0)	0.6 (0.6)
<i>Nitzschia dissipata</i> (Kützing) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	10.8 (3.5)	4.6 (2.6)	2.0 (0.3)
<i>Nitzschia fonticola</i> (Grunow) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.8)	3.0 (3.0)	0.4 (0.4)
<i>Nitzschia kutzingiana</i> Hilse	0.0 (0.0)	0.5 (0.5)	0.0 (0.0)	0.5 (0.0)	0.7 (0.7)	0.4 (0.4)
<i>Nitzschia palea</i> (Kützing) W. Smith	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	4.8 (1.9)	0.4 (0.4)	0.0 (0.0)
<i>Nitzschia</i> sp. 9	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)
<i>Pinnularia</i> sp. 1	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Pinnularia</i> sp. 2	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Pinnularia</i> sp. 3	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Planothidium frequentissimum</i> (Lange-Bertalot) Round & L. Bukhtiyarova	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Planothidium lanceolatum</i> (Brébisson ex Kützing) Lange-Bertalot	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Reimeria sinuata</i> (Gregory) Kociolek & Stoermer	0.1 (0.1)	19.2 (7.4)	2.4 (0.9)	2.3 (2.3)	13.4 (5.9)	13.3 (11.1)
<i>Rhoicosphenia curvata</i> (Kützing) Grunow	4.9 (1.4)	0.7 (0.5)	3.6 (1.7)	6.6 (2.8)	1.4 (0.9)	2.0 (0.3)
<i>Staurosira venter</i> (Ehrenberg) H. Kobayasi	1.0 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Staurosirella leptostauron</i> (Ehrenberg) D.M. Williams & Round	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Synedra acus</i> Kützing	2.3 (1.3)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Synedra amphicephala</i> var. <i>austriaca</i> (Grunow) Hustedt	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Appendix 17. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Synedra fasciculata</i> (Agardh)						
Kützing	1.1 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.6 (0.6)
<i>Synedra mazamaensis</i> Sovereign	0.3 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Synedra</i> sp. 1	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.2 (0.1)	0.2 (0.2)	0.6 (0.6)
<i>Synedra</i> sp. 2	0.6 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)
<i>Synedra ulna</i> (Nitzsch)						
Ehrenberg	4.2 (0.7)	0.0 (0.0)	0.4 (0.4)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)

Appendix 18. Mean percent abundances (SE) of algal taxa in epicremnic algal assemblages at each site during January 2007.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Achnanthes lanceolata</i> var. <i>omissa</i> Reimer	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (N/A)	0.0 (0.0)
<i>Achnanthes microcephala</i> (Kützing) Grunow/ <i>Achnanthes minutissima</i> Kützing	27.1 (14.7)	7.7 (3.8)	2.6 (2.6)	2.2 (0.8)	8.6 (N/A)	11.1 (2.0)
<i>Achnanthes sublaevis</i> var. <i>crassa</i> C.W. Reimer	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Amphora pediculus</i> (Kützing) Grunow ex A. Schmidt	0.6 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (N/A)	0.0 (0.0)
<i>Amphora perpusilla</i> (Grunow) Grunow	6.1 (3.2)	2.6 (0.7)	11.6 (6.3)	0.9 (0.9)	2.0 (N/A)	0.0 (0.0)
<i>Brachysira vitrea</i> (Grunow) R. Ross	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Cocconeis pediculus</i> Ehrenberg	5.1 (2.6)	0.0 (0.0)	3.1 (0.5)	2.8 (1.1)	2.0 (N/A)	0.0 (0.0)
<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	3.8 (2.3)	0.8 (0.8)	0.4 (0.4)	2.3 (1.5)	0.5 (N/A)	1.3 (1.3)
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehrenberg) van Heurck	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Coscinodiscus</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (0.6)	0.0 (N/A)	0.0 (0.0)
<i>Cyclotella comta</i> (Ehrenberg) Kützing	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.9 (0.6)	0.0 (N/A)	0.0 (0.0)
<i>Cymbella affinis</i> Kützing	1.1 (1.0)	0.0 (0.0)	2.2 (2.2)	3.1 (1.4)	0.5 (N/A)	0.9 (0.9)
<i>Cymbella angustata</i> (W. Smith) Cleve	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (N/A)	0.0 (0.0)
<i>Cymbella lunata</i> W. Smith	0.7 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Cymbella mexicana</i> (Ehrenberg) Cleve	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (N/A)	5.0 (2.3)
<i>Cymbella mexicana</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	1.3 (1.3)
<i>Cymbella microcephala</i> var. <i>crassa</i> Reimer	0.1 (0.1)	1.0 (1.0)	0.0 (0.0)	0.1 (0.1)	0.5 (N/A)	0.0 (0.0)
<i>Cymbella minuta</i> var. <i>silesiaca</i> (Bleisch) Reimer	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Cymbella mulleri</i> Hustedt	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Cymbella norvegica</i> sp.1	2.3 (1.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Cymbella</i> sp. 1	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Cymbella</i> sp. 2	2.4 (2.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Diatoma hiemale</i> var. <i>mesodon</i> (Ehrenberg) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.5 (N/A)	0.0 (0.0)
<i>Diatoma moniliformis</i> Kützing	0.7 (0.5)	4.1 (4.1)	0.0 (0.0)	3.0 (1.5)	4.0 (N/A)	2.7 (2.7)
<i>Diatoma</i> sp. 1	0.2 (0.2)	2.5 (2.5)	0.0 (0.0)	1.4 (1.4)	6.6 (N/A)	0.0 (0.0)
<i>Diatoma</i> sp. 2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (N/A)	0.0 (0.0)
<i>Diatoma vulgare</i> Bory	0.5 (0.3)	4.1 (4.1)	0.9 (0.9)	1.5 (1.5)	1.5 (N/A)	2.7 (2.7)
<i>Ellerbeckia arenaria</i> (Moore) R.M. Crawford	14.8 (11.5)	41.0 (14.8)	16.7 (9.6)	12.2 (2.3)	3.5 (N/A)	30.9 (7.2)

Appendix 18. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Encyonema auerswaldii</i>						
Rabenhorst	0.0 (0.0)	6.6 (6.6)	0.0 (0.0)	0.4 (0.4)	1.0 (N/A)	0.0 (0.0)
<i>Encyonema prostratum</i>						
(Berkeley) Kützing	0.0 (0.0)	2.9 (2.9)	2.2 (0.4)	3.4 (2.0)	0.0 (N/A)	2.6 (2.6)
<i>Fragilaria brevistriata</i> var.						
<i>inflata</i> (Pantocsek) Hustedt	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (N/A)	0.0 (0.0)
<i>Fragilaria capucina</i> var.						
<i>vaucheriae</i> (Kützing) Lange-						
Bertalot	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.5 (N/A)	0.0 (0.0)
<i>Fragilaria crotonensis</i> Kitton	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (N/A)	0.0 (0.0)
<i>Fragilaria</i> sp. 2	1.1 (1.1)	0.0 (0.0)	0.0 (0.0)	0.8 (0.8)	0.0 (N/A)	0.0 (0.0)
<i>Fragilaria</i> sp. 4	16.2 (6.3)	0.0 (0.0)	0.0 (0.0)	1.3 (1.3)	4.0 (N/A)	10.5 (10.5)
<i>Frustulia vulgaris</i> (Thwaites) De						
Toni	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	1.3 (1.0)	0.0 (N/A)	0.0 (0.0)
<i>Gomphonema clavatum</i>						
Ehrenberg	0.1 (0.1)	0.0 (0.0)	2.2 (2.2)	0.0 (0.0)	1.0 (N/A)	0.0 (0.0)
<i>Gomphonema olivaceum</i>						
(Hornemann) Brébisson	0.0 (0.0)	0.0 (0.0)	1.8 (1.8)	0.0 (0.0)	0.5 (N/A)	0.0 (0.0)
<i>Gomphonema olivaceum</i> var.						
<i>calcareae</i> Cleve	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	2.6 (2.6)
<i>Gomphonema parvulum</i>						
(Kützing) Kützing	0.0 (0.0)	0.0 (0.0)	0.9 (0.9)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Gomphonema truncatum</i>						
Ehrenberg	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
Green algae zoospores	0.0 (0.0)	0.0 (0.0)	39.8 (5.0)	0.0 (0.0)	0.0 (N/A)	9.1 (9.1)
<i>Gyrosigma attenuata</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.0 (N/A)	0.0 (0.0)
<i>Gyrosigma eximium</i> (Thwaites)						
Van Heurck	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (N/A)	0.0 (0.0)
<i>Gyrosigma spencerii</i> et varieties	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.7 (0.6)	0.5 (N/A)	0.0 (0.0)
<i>Hantzschia amphioxys</i>						
(Ehrenberg) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.0 (N/A)	0.0 (0.0)
<i>Martiana martyi</i> (Héribaud) F.E.						
Round	5.2 (2.5)	0.0 (0.0)	0.0 (0.0)	1.0 (0.5)	1.0 (N/A)	1.8 (1.8)
<i>Melosira varians</i> C. Agardh	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.0 (N/A)	0.0 (0.0)
<i>Navicula cryptocephala</i> Kützing	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Navicula cryptonella</i> Lange-						
Bertalot	0.6 (0.4)	1.0 (1.0)	0.0 (0.0)	2.7 (2.7)	6.6 (N/A)	0.0 (0.0)
<i>Navicula mutica</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (N/A)	0.0 (0.0)
<i>Navicula mutica</i> var. <i>cohnii</i>						
(Hilse) Grunow	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Navicula radiosa</i> Kützing	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.5 (0.2)	0.0 (N/A)	0.0 (0.0)
<i>Navicula tripunctata</i> (O.F.						
Müller) Bory	0.0 (0.0)	0.0 (0.0)	3.1 (2.2)	14.5 (0.0)	9.1 (N/A)	0.0 (0.0)
<i>Navicula veneta</i> Kützing	0.0 (0.0)	0.0 (0.0)	1.3 (1.3)	0.3 (0.3)	0.0 (N/A)	0.0 (0.0)
<i>Navicula viridula</i> (Kützing)						
Kützing	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	1.3 (1.3)

Appendix 18. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Navicula viridula</i> sp. 1	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	1.0 (N/A)	0.0 (0.0)
<i>Nitzschia amphibia</i> Grunow	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Nitzschia brevissima</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (0.6)	0.0 (N/A)	0.0 (0.0)
<i>Nitzschia capitellata</i> Hustedt	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Nitzschia denticula</i> Grunow/ <i>Denticula elegans</i> Kützing	2.2 (0.6)	2.5 (2.5)	0.4 (0.4)	0.7 (0.1)	0.5 (N/A)	0.0 (0.0)
<i>Nitzschia dissipata</i> (Kützing) Grunow	0.0 (0.0)	1.8 (0.1)	1.3 (1.3)	8.7 (8.7)	8.1 (N/A)	0.0 (0.0)
<i>Nitzschia fonticola</i> (Grunow) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.5 (N/A)	0.0 (0.0)
<i>Nitzschia kutzingiana</i> Hilse	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	5.1 (2.0)	9.1 (N/A)	0.0 (0.0)
<i>Nitzschia linearis</i> (Agardh) W. Smith	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.5 (N/A)	0.0 (0.0)
<i>Nitzschia palea</i> (Kützing) W. Smith	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	4.5 (3.7)	2.0 (N/A)	0.0 (0.0)
<i>Nitzschia</i> sp. 2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (N/A)	0.0 (0.0)
<i>Pinnularia</i> sp. 1	0.2 (0.1)	11.5 (11.5)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Planothidium frequentissimum</i> (Lange-Bertalot) Round & L. Bukhtiyarova	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.5 (N/A)	0.0 (0.0)
<i>Planothidium lanceolatum</i> (Brébisson ex Kützing) Lange- Bertalot	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (N/A)	0.0 (0.0)
<i>Reimeria sinuata</i> (Gregory) Kociolek & Stoermer	0.0 (0.0)	1.9 (1.9)	2.2 (2.2)	2.1 (1.8)	0.0 (N/A)	0.9 (0.9)
<i>Rhoicosphenia curvata</i> (Kützing) Grunow	1.1 (0.5)	0.8 (0.8)	4.9 (4.9)	1.8 (1.0)	2.5 (N/A)	5.0 (2.3)
<i>Staurosira venter</i> (Ehrenberg) H. Kobayasi	0.8 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Staurosirella leptostauron</i> (Ehrenberg) D.M. Williams & Round	0.4 (0.4)	0.0 (0.0)	0.0 (0.0)	0.8 (0.8)	0.0 (N/A)	0.0 (0.0)
<i>Surirella ovalis</i> Brébisson	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (N/A)	0.0 (0.0)
<i>Synedra acus</i> Kützing	0.7 (0.5)	0.8 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Synedra fasciculata</i> (Agardh) Kützing	0.1 (0.1)	2.5 (2.5)	0.0 (0.0)	0.1 (0.1)	0.5 (N/A)	0.0 (0.0)
<i>Synedra mazamaensis</i> Sovereign	0.0 (0.0)	0.8 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	0.0 (0.0)
<i>Synedra</i> sp. 1	0.0 (0.0)	1.6 (1.6)	0.0 (0.0)	0.0 (0.0)	0.0 (N/A)	3.5 (1.7)
<i>Synedra</i> sp. 2	0.4 (0.4)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (N/A)	0.0 (0.0)
<i>Synedra ulna</i> (Nitzsch) Ehrenberg	1.8 (0.6)	1.6 (1.6)	1.3 (1.3)	13.6 (8.5)	8.1 (N/A)	6.6 (6.6)

Appendix 19. Mean percent abundances (SE) of algal taxa in *Simulium arcticum* diets at each site during January 2007.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Achnanthes microcephala</i> (Kützing) Grunow/ <i>Achnanthes minutissima</i> Kützing	5.0 (0.3)	16.7 (1.4)	26.7 (0.8)	18.4 (1.5)	11.1 (2.1)	18.6 (4.3)
<i>Amphora pediculus</i> (Kützing) Grunow ex A. Schmidt	0.1 (0.1)	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Amphora perpusilla</i> (Grunow) Grunow	1.5 (0.2)	1.2 (0.3)	5.0 (2.3)	3.3 (1.1)	2.4 (0.5)	2.5 (0.9)
<i>Aneumastus tuscula</i> (Ehrenberg) D.G. Mann & A.J. Stickle	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Bacillaria paradoxa</i> J.F. Gmelin	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Brachysira vitrea</i> (Grunow) R. Ross	1.0 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)
<i>Cavinula cocconeiformis</i> (Gregory ex Greville) D.G. Mann & A.J. Stickle	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cladophora glomerata</i> (Linnaeus) Kützing	0.0 (0.0)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)	0.3 (0.2)	0.2 (0.2)
<i>Cocconeis neodiminuta</i> Krammer	0.0 (0.0)	0.4 (0.2)	0.3 (0.2)	0.2 (0.1)	0.2 (0.2)	0.2 (0.2)
<i>Cocconeis pediculus</i> Ehrenberg	4.7 (0.7)	14.1 (2.5)	9.9 (2.2)	9.0 (1.0)	14.8 (1.0)	7.7 (1.2)
<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	2.5 (0.4)	3.0 (0.8)	5.9 (2.3)	3.9 (1.2)	5.0 (1.2)	3.2 (1.5)
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehrenberg) van Heurck	0.4 (0.4)	1.8 (0.7)	2.9 (1.6)	1.6 (0.6)	2.8 (0.5)	0.6 (0.4)
<i>Coscinodiscus</i> sp. 1	0.1 (0.1)	0.0 (0.0)	0.4 (0.4)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)
<i>Craticula accomoda</i> (Hustedt) D.G. Mann	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Cyclotella comta</i> (Ehrenberg) Kützing	2.1 (0.4)	1.2 (0.6)	0.2 (0.2)	0.6 (0.1)	0.2 (0.1)	0.6 (0.3)
<i>Cyclotella meneghiniana</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	1.0 (0.1)	1.6 (0.3)	0.0 (0.0)
<i>Cyclotella</i> sp. 1	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella affinis</i> Kützing	0.0 (0.0)	0.2 (0.2)	0.7 (0.2)	0.6 (0.1)	0.4 (0.2)	0.2 (0.2)
<i>Cymbella amphicephala</i> Näegeli	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.2 (0.1)	0.3 (0.3)
<i>Cymbella cymbiformis</i> var. <i>nonpunctata</i> Fontell	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella mexicana</i> (Ehrenberg) Cleve	0.2 (0.1)	0.5 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.2 (0.2)
<i>Cymbella microcephala</i> var. <i>crassa</i> Reimer	0.5 (0.2)	0.6 (0.3)	0.5 (0.3)	0.7 (0.5)	0.9 (0.5)	0.8 (0.5)
<i>Cymbella</i> sp. 1	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)
<i>Diatoma hiemale</i> var. <i>mesodon</i> (Ehrenberg) Grunow	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)
<i>Diatoma moniliformis</i> Kützing	3.1 (0.4)	7.2 (0.9)	3.2 (1.0)	7.2 (1.6)	3.7 (0.9)	11.4 (0.6)
<i>Diatoma</i> sp. 1	1.1 (0.3)	5.7 (0.8)	3.7 (0.7)	11.0 (0.6)	7.8 (0.4)	6.8 (2.0)
<i>Diatoma</i> sp. 2	0.3 (0.1)	0.1 (0.1)	0.2 (0.2)	2.0 (0.6)	0.9 (0.1)	0.5 (0.5)

Appendix 19. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Diatoma tenue</i> var. <i>elongatum</i>						
Lyngbye	0.2 (0.2)	0.5 (0.4)	0.3 (0.3)	0.1 (0.1)	0.3 (0.2)	0.0 (0.0)
<i>Diatoma vulgare</i> Bory	8.9 (1.6)	1.5 (0.9)	0.5 (0.5)	1.9 (0.7)	0.9 (0.3)	2.8 (0.7)
<i>Ellerbeckia arenaria</i> (Moore)						
R.M. Crawford	1.3 (0.7)	0.2 (0.2)	0.2 (0.2)	0.3 (0.1)	0.6 (0.3)	0.2 (0.2)
<i>Encyonema auerswaldii</i>						
Rabenhorst	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.5 (0.3)	0.8 (0.1)	1.1 (0.3)
<i>Encyonema minutum</i> (Hilse in Rabenhorst) D.G. Mann	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Encyonema prostratum</i> (Berkeley) Kützing	0.2 (0.1)	0.1 (0.1)	0.5 (0.4)	0.4 (0.2)	0.2 (0.1)	1.5 (0.4)
<i>Entomoneis alata</i> (Ehrenberg)						
Ehrenberg	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Filamentous algae sp. 1	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria crotonensis</i> Kitton	55.8 (2.8)	15.4 (5.9)	8.8 (2.4)	4.7 (0.4)	1.7 (0.5)	9.7 (2.3)
<i>Fragilaria</i> sp. 2	1.8 (1.3)	2.3 (1.2)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)	0.3 (0.3)
<i>Fragilaria</i> sp. 4	1.2 (0.6)	3.0 (2.0)	3.5 (2.1)	2.5 (1.2)	7.5 (1.6)	3.4 (1.0)
<i>Frustulia vulgaris</i> (Thwaites) De Toni	0.0 (0.0)	0.0 (0.0)	0.3 (0.2)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)
<i>Gomphonema olivaceum</i> (Hornemann) Brébisson	0.0 (0.0)	0.9 (0.9)	0.2 (0.2)	1.1 (0.1)	0.6 (0.6)	0.5 (0.5)
<i>Gomphonema olivaceum</i> var. <i>calcareum</i> Cleve	0.6 (0.2)	7.1 (5.9)	1.4 (0.9)	0.8 (0.3)	0.6 (0.5)	2.2 (0.3)
<i>Gomphonema</i> sp. 2	0.0 (0.0)	0.4 (0.4)	0.8 (0.3)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)
<i>Gyrosigma eximium</i> (Thwaites) Van Heurck	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (0.8)	0.4 (0.4)	0.2 (0.2)
<i>Gyrosigma spencerii</i> et varieties	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.1 (0.1)	0.5 (0.5)
<i>Martiana martyi</i> (Hérilaud) F.E. Round	0.1 (0.1)	0.7 (0.5)	0.3 (0.2)	0.5 (0.3)	1.8 (0.9)	0.0 (0.0)
<i>Melosira varians</i> C. Agardh	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.8 (0.5)	1.6 (1.3)
<i>Navicula cryptocephala</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.4 (0.4)
<i>Navicula cryptonella</i> Lange-Bertalot	0.1 (0.1)	0.4 (0.2)	1.6 (0.2)	0.8 (0.1)	1.1 (0.5)	1.4 (0.5)
<i>Navicula minima</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Navicula pupula</i> var. <i>rectangularis</i> (W. Gregory) Cleve & Grunov	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Navicula tripunctata</i> (O.F. Müller) Bory	0.1 (0.1)	0.5 (0.4)	0.4 (0.4)	1.4 (0.4)	1.2 (0.6)	1.2 (0.6)
<i>Navicula veneta</i> Kützing	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia acicularis</i> (Kützing) W. Smith	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	1.4 (1.4)	0.1 (0.1)	0.0 (0.0)
<i>Nitzschia amphibia</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Nitzschia apiculata</i> (W. Gregory) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.2)	0.0 (0.0)
<i>Nitzschia austriaca</i> Hustedt	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)

Appendix 19. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Nitzschia denticula</i>						
Grunow/ <i>Denticula elegans</i>						
Kützing	0.1 (0.1)	0.4 (0.2)	0.0 (0.0)	0.0 (0.0)	0.3 (0.0)	0.0 (0.0)
<i>Nitzschia dissipata</i> (Kützing)						
Grunow	0.2 (0.1)	0.2 (0.1)	4.7 (0.3)	5.0 (0.2)	3.9 (1.0)	4.2 (1.1)
<i>Nitzschia kutzingiana</i> Hilse	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
<i>Nitzschia linearis</i> (Agardh) W. Smith	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)
<i>Nitzschia sigma</i> (Kützing) W. Smith	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia</i> sp. 2	0.1 (0.1)	0.2 (0.1)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.3 (0.3)
<i>Nitzschia</i> sp. 3	0.1 (0.1)	0.2 (0.2)	0.4 (0.3)	0.2 (0.2)	0.3 (0.3)	0.0 (0.0)
<i>Pinnularia</i> sp. 1	0.4 (0.2)	0.1 (0.1)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Planothidium lanceolatum</i> (Brébisson ex Kützing) Lange-Bertalot	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)
<i>Reimeria sinuata</i> (Gregory)						
Kociolek & Stoermer	0.0 (0.0)	0.3 (0.2)	0.2 (0.2)	1.9 (0.5)	1.1 (0.3)	1.4 (0.5)
<i>Rhoicosphenia curvata</i> (Kützing)						
Grunow	3.4 (0.5)	7.5 (2.4)	8.0 (1.3)	9.8 (1.7)	16.7 (1.8)	8.0 (1.7)
<i>Sellaphora pupula</i> (Kützing)						
Mereschkovsky	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.4 (0.2)
<i>Staurosira venter</i> (Ehrenberg) H. Kobayasi	0.2 (0.1)	1.1 (0.5)	2.0 (0.8)	1.3 (0.6)	0.5 (0.3)	1.2 (0.7)
<i>Staurosirella leptostauron</i> (Ehrenberg) D.M. Williams & Round	0.2 (0.2)	0.3 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)
<i>Surirella ovalis</i> Brébisson	0.0 (0.0)	0.0 (0.0)	2.1 (0.3)	0.1 (0.1)	0.5 (0.4)	0.0 (0.0)
<i>Synedra acus</i> Kützing	0.0 (0.0)	0.8 (0.4)	0.4 (0.4)	0.3 (0.2)	0.7 (0.6)	0.2 (0.2)
<i>Synedra capitata</i> Ehrenberg	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Synedra delicatissima</i> var. <i>angustissima</i> Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Synedra fasciculata</i> (Agardh) Kützing	0.3 (0.2)	0.1 (0.1)	0.0 (0.0)	0.4 (0.4)	0.5 (0.1)	0.8 (0.8)
<i>Synedra goulardi</i> Brébisson	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
<i>Synedra mazamaensis</i> Sovereign	0.3 (0.3)	0.1 (0.1)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Synedra parasitica</i> var. <i>parasitica</i> (W. Smith) Hustedt	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
<i>Synedra ulna</i> (Nitzsch) Ehrenberg	1.6 (0.6)	1.8 (0.3)	2.1 (0.4)	2.2 (0.1)	1.5 (0.5)	1.1 (0.5)
<i>Synedra ulna</i> var. <i>contracta</i> Østrup	0.0 (0.0)	0.3 (0.2)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.2 (0.2)

Appendix 20. Mean percent abundances (SE) of algal taxa in *Gammarus lacustris* diets at each site during January 2007.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Achnanthes microcephala</i> (Kützing) Grunow/ <i>Achnanthes minutissima</i> Kützing	5.8 (0.9)	18.9 (3.5)	7.3 (5.1)	2.6 (1.1)	5.2 (2.5)	3.1 (1.6)
<i>Amphora pediculus</i> (Kützing) Grunow ex A. Schmidt	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Amphora perpusilla</i> (Grunow) Grunow	0.8 (0.1)	0.0 (0.0)	6.3 (5.4)	0.0 (0.0)	1.3 (0.7)	0.0 (0.0)
<i>Brachysira vitrea</i> (Grunow) R. Ross	3.4 (1.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cladophora glomerata</i> (Linnaeus) Kützing	0.5 (0.3)	0.0 (0.0)	2.1 (1.1)	0.0 (0.0)	3.5 (2.3)	1.1 (1.1)
<i>Cocconeis neodiminuta</i> Krammer	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cocconeis pediculus</i> Ehrenberg	17.6 (1.0)	2.4 (0.0)	31.3 (16.9)	19.5 (6.4)	19.3 (8.9)	5.9 (3.5)
<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehrenberg) Grunow	2.8 (1.4)	2.7 (0.8)	0.8 (0.8)	4.4 (3.0)	0.9 (0.9)	2.8 (2.3)
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehrenberg) van Heurck	1.2 (0.4)	0.0 (0.0)	4.9 (3.8)	0.7 (0.7)	0.5 (0.5)	1.2 (0.7)
<i>Coscinodiscus</i> sp. 1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)
<i>Cyclotella comta</i> (Ehrenberg) Kützing	0.5 (0.1)	0.0 (0.0)	0.8 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cyclotella meneghiniana</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.8 (0.8)	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella affinis</i> Kützing	0.0 (0.0)	2.9 (2.9)	1.6 (0.8)	0.0 (0.0)	0.9 (0.9)	0.0 (0.0)
<i>Cymbella cymbiformis</i> var. <i>nonpunctata</i> Fontell	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella mexicana</i> (Ehrenberg) Cleve	0.7 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Cymbella microcephala</i> var. <i>crassa</i> Reimer	0.0 (0.0)	2.9 (0.5)	0.0 (0.0)	0.0 (0.0)	0.9 (0.9)	0.0 (0.0)
<i>Cymbella</i> sp. 1	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma hiemale</i> var. <i>mesodon</i> (Ehrenberg) Grunow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.8 (0.8)
<i>Diatoma moniliformis</i> Kützing	1.2 (0.8)	3.1 (1.7)	2.4 (2.4)	0.0 (0.0)	0.0 (0.0)	3.8 (1.4)
<i>Diatoma</i> sp. 1	1.2 (0.4)	3.1 (1.7)	0.8 (0.8)	0.0 (0.0)	0.0 (0.0)	1.6 (1.6)
<i>Diatoma tenue</i> var. <i>elongatum</i> Lyngbye	0.0 (0.0)	1.3 (0.1)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)
<i>Diatoma vulgare</i> Bory	13.0 (4.0)	1.8 (1.8)	0.0 (0.0)	1.9 (1.9)	2.2 (0.4)	0.8 (0.8)
<i>Didymosphenia geminata</i> (Lyngbye) M. Schmidt	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Ellerbeckia arenaria</i> (Moore) R.M. Crawford	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Encyonema auerswaldii</i> Rabenhorst	0.0 (0.0)	0.5 (0.5)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	8.9 (8.9)
<i>Encyonema minutum</i> (Hilse in Rabenhorst) D.G. Mann	0.0 (0.0)	0.6 (0.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Appendix 20. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Encyonema prostratum</i>						
(Berkeley) Kützing	0.0 (0.0)	0.0 (0.0)	0.8 (0.8)	0.7 (0.7)	0.0 (0.0)	0.4 (0.4)
Filamentous algae sp. 2	0.0 (0.0)	0.5 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria capucina</i> var. <i>vaucheriae</i> (Kützing) Lange- Bertalot	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria crotonensis</i> Kitton	0.4 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Fragilaria</i> sp. 2	4.6 (4.0)	0.0 (0.0)	15.1 (15.1)	19.4 (0.9)	4.3 (4.3)	13.0 (6.7)
<i>Fragilaria</i> sp. 4	23.8 (7.1)	24.3 (2.9)	0.0 (0.0)	15.2 (15.2)	24.7 (12.5)	21.8 (16.1)
<i>Gomphonema olivaceum</i> (Hornemann) Brébisson	2.1 (0.5)	0.5 (0.5)	0.0 (0.0)	0.0 (0.0)	2.6 (2.6)	1.2 (0.7)
<i>Gomphonema olivaceum</i> var. <i>calcareum</i> Cleve	0.6 (0.2)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Gomphonema</i> sp. 2	0.3 (0.3)	2.1 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Gyrosigma eximium</i> (Thwaites) Van Heurck	0.0 (0.0)	0.6 (0.6)	2.8 (2.3)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)
<i>Martyana martyi</i> (Héribaud) F.E. Round	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Melosira varians</i> C. Agardh	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.6 (1.6)
<i>Navicula cryptocephala</i> Kützing	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.4 (0.4)
<i>Navicula cryptonella</i> Lange- Bertalot	0.4 (0.3)	3.5 (2.3)	9.7 (8.6)	0.0 (0.0)	0.9 (0.9)	0.0 (0.0)
<i>Navicula rostellata</i> Kützing	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Navicula tripunctata</i> (O.F. Müller) Bory	0.1 (0.1)	0.2 (0.2)	0.8 (0.8)	0.0 (0.0)	1.7 (0.9)	0.4 (0.4)
<i>Navicula veneta</i> Kützing	0.1 (0.1)	0.0 (0.0)	0.8 (0.8)	1.9 (1.9)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia denticula</i> Grunow/ <i>Denticula elegans</i> Kützing	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia dissipata</i> (Kützing) Grunow	0.0 (0.0)	1.0 (1.0)	3.5 (1.9)	1.4 (1.4)	0.9 (0.9)	3.3 (2.2)
<i>Nitzschia fonticola</i> (Grunow) Grunow	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia linearis</i> (Agardh) W. Smith	0.0 (0.0)	0.0 (0.0)	1.6 (1.6)	0.0 (0.0)	0.5 (0.5)	0.8 (0.8)
<i>Nitzschia</i> sp. 3	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Nitzschia</i> sp. 9	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Pinnularia</i> sp. 1	0.1 (0.1)	0.0 (0.0)	0.8 (0.8)	0.0 (0.0)	0.9 (0.9)	0.8 (0.8)
<i>Reimeria sinuata</i> (Gregory) Kociolek & Stoermer	0.1 (0.1)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.4 (1.4)
<i>Rhoicosphenia curvata</i> (Kützing) Grunow	12.1 (2.0)	8.7 (4.4)	2.4 (1.4)	12.5 (2.3)	7.5 (1.6)	5.8 (3.0)

Appendix 20. Continued.

Taxon	RM 0	RM 30	RM 62	RM 127	RM 165	RM 225
<i>Stauroneis</i> sp. 1	0.0 (0.0)	1.2 (1.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
<i>Staurosira venter</i> (Ehrenberg) H. Kobayasi	0.8 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (0.5)	0.0 (0.0)
<i>Surirella minuta</i> Brébisson	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.4 (1.4)	0.0 (0.0)	3.3 (3.3)
<i>Surirella ovalis</i> Brébisson	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.9 (0.9)	0.0 (0.0)
<i>Synedra acus</i> Kützing	0.2 (0.2)	0.0 (0.0)	0.3 (0.3)	0.7 (0.7)	0.5 (0.5)	0.8 (0.8)
<i>Synedra fasciculata</i> (Agardh) Kützing	0.0 (0.0)	1.4 (1.0)	0.0 (0.0)	13.6 (4.9)	11.4 (1.6)	7.2 (4.9)
<i>Synedra ulna</i> (Nitzsch) Ehrenberg	4.4 (1.3)	14.8 (1.9)	1.1 (0.7)	2.6 (1.1)	8.5 (4.7)	5.9 (0.7)
<i>Synedra ulna</i> var. <i>contracta</i> Østrup	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

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VITA

Holly Ann Wellard Kelly graduated from Michigan State University with a Bachelor of Science in Zoology in 2003. Her undergraduate work included a summer internship monitoring hawksbill turtles in Hawaii Volcanoes National Park. After graduating she worked as an intern and research technician on a number of projects. Her internship with NOAA involved studying chinook salmon stream ecosystems in the Salmon River Basin of Idaho. She also worked as a fisheries technician on a lake sturgeon restoration project in Black Lake, Michigan, and for the Institute for Fisheries Research/Streams Status and Trends Program, where she helped to develop and refine an assessment protocol to identify the physical habitat features most relevant to fish assemblages of Michigan's non-wadeable rivers. In the summer of 2006, Holly was awarded a Research Assistantship with Dr. Emma Rosi-Marshall at Loyola University Chicago, and began her work on the Colorado River investigating macroinvertebrate resource consumption. While at Loyola she participated in seven river trips including a sampling trip to collect samples during the experimental high-flow release in 2008. She also served as a research assistant on a project investigating the effects of temperature and diel fluctuations in water velocity on basal resources, using Loyola's artificial stream facility. Currently, Holly is living in Oregon with her husband Sam.

THESIS APPROVAL SHEET

The thesis submitted by Holly A. Wellard Kelly has been read and approved by the following committee:

Emma Rosi-Marshall, Ph.D., Director
Professor of Biology
Loyola University Chicago/Cary Institute of Ecosystem Studies

Martin Berg, Ph.D.
Professor of Biology
Loyola University Chicago

Christopher Peterson, Ph.D.
Professor of Natural Sciences
Loyola University Chicago

Ted Kennedy, Ph.D.
Aquatic Biologist
Grand Canyon Monitoring & Research Center
United States Geological Survey

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

march 31, 2010

Date

A handwritten signature in black ink, appearing to read 'Emma Rosi-Marshall', written over a horizontal line.

Director's Signature